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RESEARCH PROJECT INITIATION

Date: June 15, 1972

Project Title: Exploratory Development on Polyester/Wool Uniform Fabrics with Improved Durability and Appearance

Project No: E-27-613

Principal Investigator Dr. W. D. Freeston, Jr.

Sponsor: Hq. 4950th Test Wing (AFSC); Wright-Patterson AFB, Ohio 45433

Agreement Period: From May 15, 1972 Until November 15, 1973

Type Agreement: Contract No. F33615-72-C-1822

Amount: $159,857.00 (Partially funded at $45,000 thru 10-15-72)

Reports Required: Bi-Monthly Status Reports; Interim (Semi-annual) Technical Reports; Final Technical Report; Material Specification.

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Defense Priority Rating: DO-C9 under DMS Reg. 1

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Date: January 16, 1976

Project Title: Exploratory Development on Polyester/Wool Uniform Fabrics with Improved Durability and Appearance

Project No: E-27-613

Principal Investigator: Dr. W. D. Freeston 2490

Sponsor: Hq. 4950th Test Wing (AFSC); Wright-Patterson AFB, OH 45433

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E-27-613

Bimonthly Status Report Number 1

(15 May to 15 July 1972)

Exploratory Development on Polyester/Wool Uniform Fabric with Improved Durability and Appearance

Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

(Prepared under Contract No. F33615-72-C-1822

by Georgia Institute of Technology, Atlanta, Georgia,

W. C. Carter, author)

Abstract

Comprehensive examination of a worn, frosted uniform supplied by the Air Force Materials Laboratory has been made to determine the cause of the observed frosting. It is concluded that the fiber responsible for the change in appearance due to wear in this 60/40 polyester/wool blend fabric is the polyester fiber. Although the wool component is preferentially abraded and removed, this does not lead to a frosted appearance. When the polyester is abraded, the fiber becomes fibrillated. The light scattered by the polyester fibrils is responsible for the frosted appearance.

A laboratory study of the flat-abrasion of a standard Air Force Blue 1549 fabric leads to the same conclusion, i.e. the polyester fiber is responsible for the change in appearance.

To establish current practice with respect to the choice of polyester and processing procedures, contacts have been or are being made with the polyester fiber producers, dyestuff manufacturers, and textile firms who specialize in polyester/wool worsted fabrics. The status of these inquiries is included in this report.

TABLE CONTENTS

I. Introduction

The purpose of this program is to develop polyester/wool Air Force Blue 1549 fabrics having improved drape, handle, fabricability, wear, and resistance to frosting over current Air Force fabrics. To achieve these objectives, an investigation of the effects of the type polyester used, the ratio of polyester fiber to wool, yarn and fabric construction, and the dyeing and finishing processes used, on fabric properties is required. In particular, fabric properties such as drape, handle, fabricability, and resistance to wear should be studied in depth to determine the effect of the above mentioned variables on them. In the first phase of this program, attention has been directed to the problem of frosting which has been defined as

> "a change of fabric color caused by localized abrasive wear. It may be the result of differential wear, as in multi-component blends in which the fibers do not match in shade, or of the abrasion of single fiber constructions in which there is a variation in or incomplete penetration of dyestuff. Frosting is sometimes referred to as 'differential wear' or 'fibrillation.'"[1]

Although the frosting has been used to describe the appearance of abraded polyester/cotton, polyester/rayon, and polyester/wool fabrics, most of the published information indicates several possible causes for the objectionable changes in fabric appearance due to abrasion with no assessment of their relative importance in the problem.

One of the usual explanations is that the two fiber components are not dyed to a solid (i.e., the same) shade and the change in appearance due to wear is a result of the differential wear of the two fiber components. This explanation cannot be used for the Air Force Blue 1549 fabric in which the polyester and wool fibers are dyed to a near solid shade. Therefore, for this fabric, it must be established whether the change in appearance is due to a change in appearance of the wool component or that of the polyester component. A comprehensive understanding of the mechanism of frosting of this fabric should lead to possible means for improving its resistance to abrasion through the choice of the best polyester fiber, best dyeing and finishing processes, and yarn and fabric construction.

A meeting was held with the Air Force Materials Laboratory personnel in Dayton, Ohio, to discuss details of this contract, particularly dates for delivery of reports and materials to the contractor. In addition, Georgia Tech was supplied with considerable background material for the project. Standard Air Force Blue 1549 fabrics were also supplied.

II. Frosting of Polyester/Wool Air Force Blue 1549 Fabric: Its Cause

A. Study of Worn Air Force Uniform

A worn Air Force uniform has been studied to gain an understanding of the "frosting" problem. The entire uniform was not available and only a sleeve of the uniform was supplied by the Air Force Materials Laboratory. The uniform had been worn 110 times and dry-cleaned 44 times. Badly frosted and unfrosted areas of the fabric were examined optically at low power (~40x) and at higher magnifications (up to 500x) using the scanning electron microscope. In order to establish which of the two fibers was responsible for the frosted appearance, the wool component was removed by treating the fabrics with a 5.0% solution of sodium hypochlorite. This removal of wool was found to be quantitative with no apparent damage to the polyester fiber and with no effect on the dye in the fiber. The fabrics resulting from this treatment were similarly examined by optical microscopy and scanning electron microscopy.

At low magnification, it is apparent that many fibers have been abraded away leaving fiber ends which have a crystalline appearance, free of dye. At higher magnification (SEM), the broken ends of the damaged polyester fibers are shown to be highly fibrillated whereas those of wool are blunt in appearance with little fibrillation. The cuticle is missing from some damaged wool fibers. A comparison of the frosted and unfrosted fabrics, before and after the removal of wool, leads to the following conclusions:

1. There is a differential wear of the two fibers, wool being more easily damaged.

2. The polyester component is damaged, leading to fiber ends which are highly fibrillated.

3. The frosted appearance of the worn area is unchanged by the removal of wool, showing conclusively that the polyester fiber is responsible for the frosted appearance.

4. The highly fibrillated polyester fibers are good light scatterers leading to an increase in the luminosity of the fabric which is referred to as frosting.

B. Study of the Flat-Abrasion of Air Force Blue 1549 Fabric

A study has been made of the resistance to flat-abrasion of the Air Force Blue 1549 fabric to determine whether the frosting produced has the same character as that produced in the worn uniform fabric. In addition, it was desirable to know the severity of testing that should be used in studying the effect of various modified fabric constructions, fiber processing procedures, and wet processing procedures on the abrasion resistance of the uniform fabric in order to produce an improved product.

The flat-abrasion test used is that described in the Technical Manual of the American Association of Textile Chemists and Colorists, Test Method 119-1970.[1] This test calls for the Stoll Universal Wear Tester Model CS-22C with a frosting attachment. The abrading surface in the method is a standard stainless steel wire screen. A single test by this method consists of 1200 abrasion cycles. The Blue 1549 fabric was subjected to 14,400 cycles of abrasion in 1200 cycle increments. Each abraded sample was examined microscopically (~40x) and the change in color estimated by comparison with a standard geometric grey scale as specified in the test and by quantitative color measurements using the I.D.L. Color Eye. The fabrics were then washed in Stoddard solvent and color measurements made. Following this, the wool component was removed with aqueous sodium hypochlorite. After conditioning, the color of the fabrics was again determined.

The measured color of each abraded sample was compared with that of a control unabraded sample. The color differences are expressed in terms of MacAdams color difference units: ΔE, total color difference, ΔL difference in lightness, and ΔC, chromaticity difference. The results are shown in Figures 1 through 4. The change in ΔE and ΔL with increasing abrasion is in good agreement with the changes noted visually and correlate well with the ratings for the degree of frosting expressed in terms of a standard geometric grey scale of color difference. Up to 3600 cycles, the frosting is negligible, corresponding to a 4 to 5 rating on the geometric grey scale. The small measured color changes is probably due to the initial chromaticity change resulting from the preferential damage and removal of surface wool fibers. Frosting is barely perceptible at 4800 cycles. At 7200 cycles, the polyester fibers become severely damaged but not broken away from the fabric. Further abrasion, up to 12,000 cycles, leads to a breaking away and removal of the damaged fibers with little change in frosting. At 13,200 cycles there is again a larger increase in frosting. It would appear from Figure 1 that the frosting occurs in stages. This is less apparent after washing with Stoddard solvent. A comparison of Figure 2 and 3 clearly shows that the polyester fiber is primarily responsible for the color change. Both the trends and magnitudes of the ΔE and ΔL values are the same for the blend fabric and the fabric containing polyester fiber alone.

The results of this work indicate that in order to improve the durability of the fabric, the most durable polyester fiber must be used (probably a Dacron 54 type fiber) and the dyeing and finishing conditions must be chosen which will cause minimum damage to wool. Thus, the carbonization of the fabric should be avoided as well as the use of mineral acids in dyeing.

III. Examination of Current Practice in the Production of the Air Force Blue 1549 Fabric

In this program, only small changes in yarn and fabric construction can be made in order to achieve a fabric with improved durability due to the required fabric specifications. Therefore, the most obvious ways to improve fabric properties are

1. choice of polyester fiber,
2. the proportion of polyester and wool in the fabric,
3. choice of dyeing and finishing processes which minimize damage to both fiber components,
4. lubricating finish on fabric.

To establish current practice with respect to choice of polyester and processing procedures, the following contacts have been or are being made:

1. Polyester fiber producers and the Wool Bureau,
2. Dyestuff manufacturers,
3. Textile firms who make Air Force Blue 1549 fabric.

A. Polyester Fiber Producers

The following producers of polyester fibers have been contacted:

1. American Enka Corporation
2. FMC Corporation
3. Celanese Corporation (Fiber Industries, Inc.)
4. Monsanto Company
5. Hystron Fibers, Inc.
6. Tennessee Eastman Co.
7. Hoechst Fibers, Inc.
8. E.I. du Pont de Nemours, Inc.

Many of these companies have not responded. Those responding were able to supply little or no information relative to the problem of frosting and recommendations for possible means for improving the fabric. This became understandable when it was learned that duPont probably has 80 to 90 percent of the business in polyester/wool fabrics.

On June 27, 1972, a trip was made to Wilmington to discuss with duPont personnel the problem of frosting and their recommendations with respect to the application of duPont's polyester fibers in Air Force uniform fabrics. A copy of this trip report is appended.

The duPont personnel were very knowledgeable of the problem and had some positive recommendations to make with respect to fiber choice and processing conditions. They have examined in some detail the same worn uniform examined at Georgia Tech. They concluded that the change in appearance (i.e., frosting) of the uniform is due to the polyester component. Their experimental results are in complete agreement with those found by Georgia Tech. They also conclude that the mechanism of frosting is independent of the polyester fiber used although the magnitude of frosting will depend on the type polyester used. Dacron 54 is recommended because of its superior durability and toughness compared with others that are used, namely Dccron 64, Dacron 59, and Dacron 35. Dacron 54 is a less-fibrillating fiber. In spite of these recommendations, they stated that a considerable amount of Dacron 64 is used for uniform fabrics rather than Dacron 54.

With respect to fiber and fabric processing proeedures which could lead to improved properties, they recommend that carbonizing of the fabric should be avoided since it results in damage to both fibers. They also recommend dyeing procedures which will result in minimum fiber damage and finishing processes which will provide good fiber mobility, e.g., milling and dolly working.

An integral part of the wearing process is the dry cleaning step between wearings. No investigation has been made of its effect on abrasion resistance. Many dry-cleaning establishments use perchloroethylene as a solvent. This solvent is sorbed by polyester fiber and when the fabric is subjected to steam pressing could cause structural changes in the fiber making it more susceptible to mechanical damage during wearing. Even if no solvent is retained, the steam pressing treatment may cause similar structural changes which adversely affect uniform durability.

B. Dye Manufacturers

Based on the fastness requirements for military uniforms, it is concluded that the classes of dyes which will be used in this study are

1. For wool component
   a. Acid metalized dyes
   b. Mordant dyes
   c. Neutral dyeing metalized dyes
2. For polyester component
   a. Disperse dyes

Those dye manufacturers who specialize in making these classes of dyes are being contacted to obtain their dye recommendations, the reflectance spectra for these dyes to assist in color matching, their fastness properties, and the recommended dyeing procedures.

C. Textile Manufacturers of Air Force Blue 1549 Fabric

The important textile processing details which affect the properties of the finished fabric will be supplied by worsted fabric manufacturers.

This transfer of information will be accomplished through meetings with appropriate knowledgeable representatives of two companies. Work statements for subcontracts to these textile manufacturers as well as a detailed agenda for the first meeting with them have been prepared and forwarded to the Air Force Materials Laboratory.

IV. Future Work

Work during the next two months will be concentrated on establishing:

A. Which three polyester fibers will be considered for the Air Force fabric

B. The effect of wet processing conditions on the abrasion of the blend fabric (conditions which lead to poor dye penetration, chemical damage during wet processing)

C. The choice of dyes for both fibers and starting dyeing formulations to match the Air Force Blue shade.

REFERENCES

1. AATCC Test Method 119-1970, Technical Manual of the American Association of Textile Chemists and Colorists, 1970, p. 108.

Fig1 Flat Abrasion of Air Force Blue 1549 Fabric

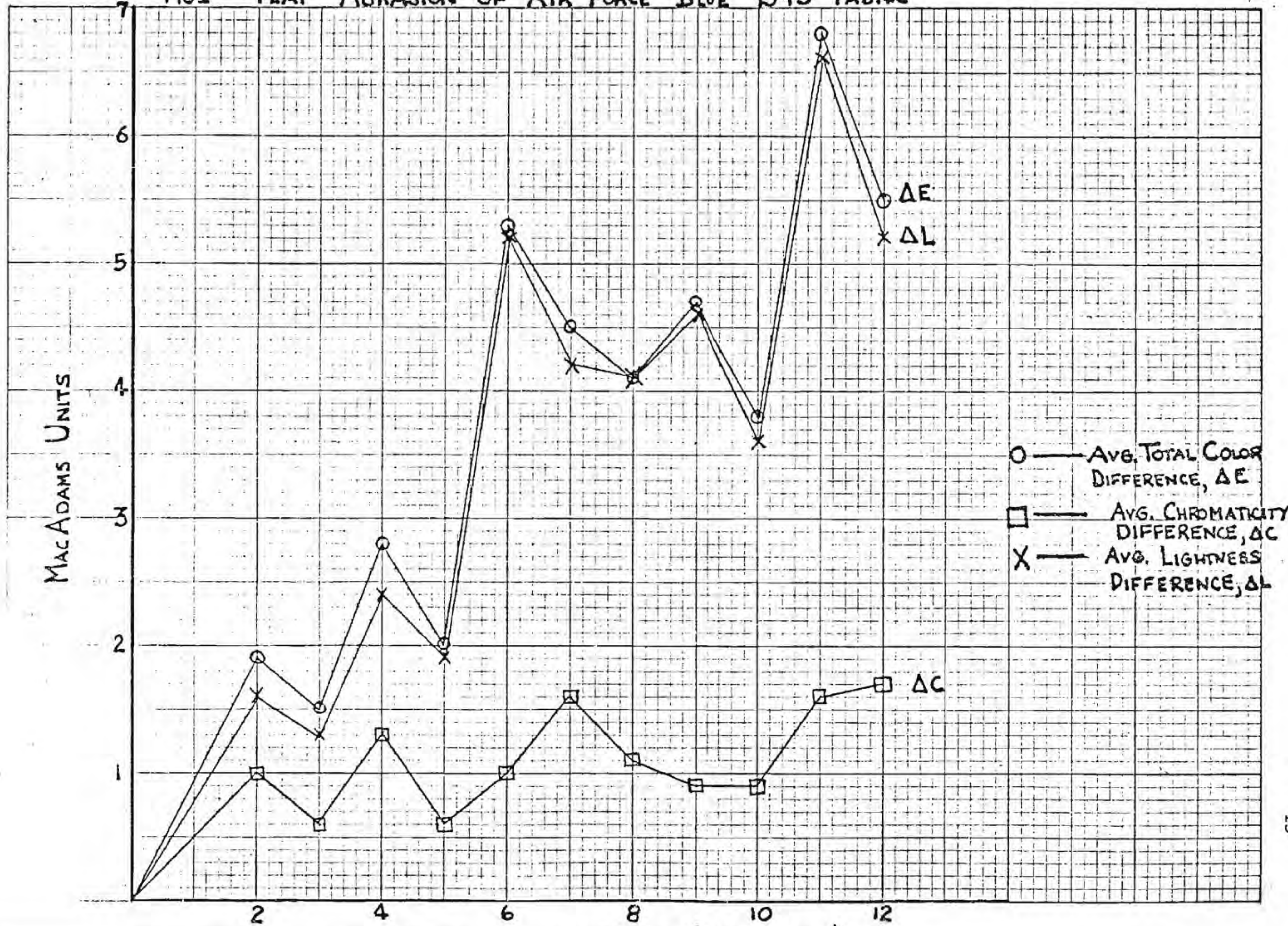


FIG 2 FLAT ABRASION OF AIR FORCE BLUE 1549 FABRIC
FABRIC WASHED IN STODDARD SOLVENT

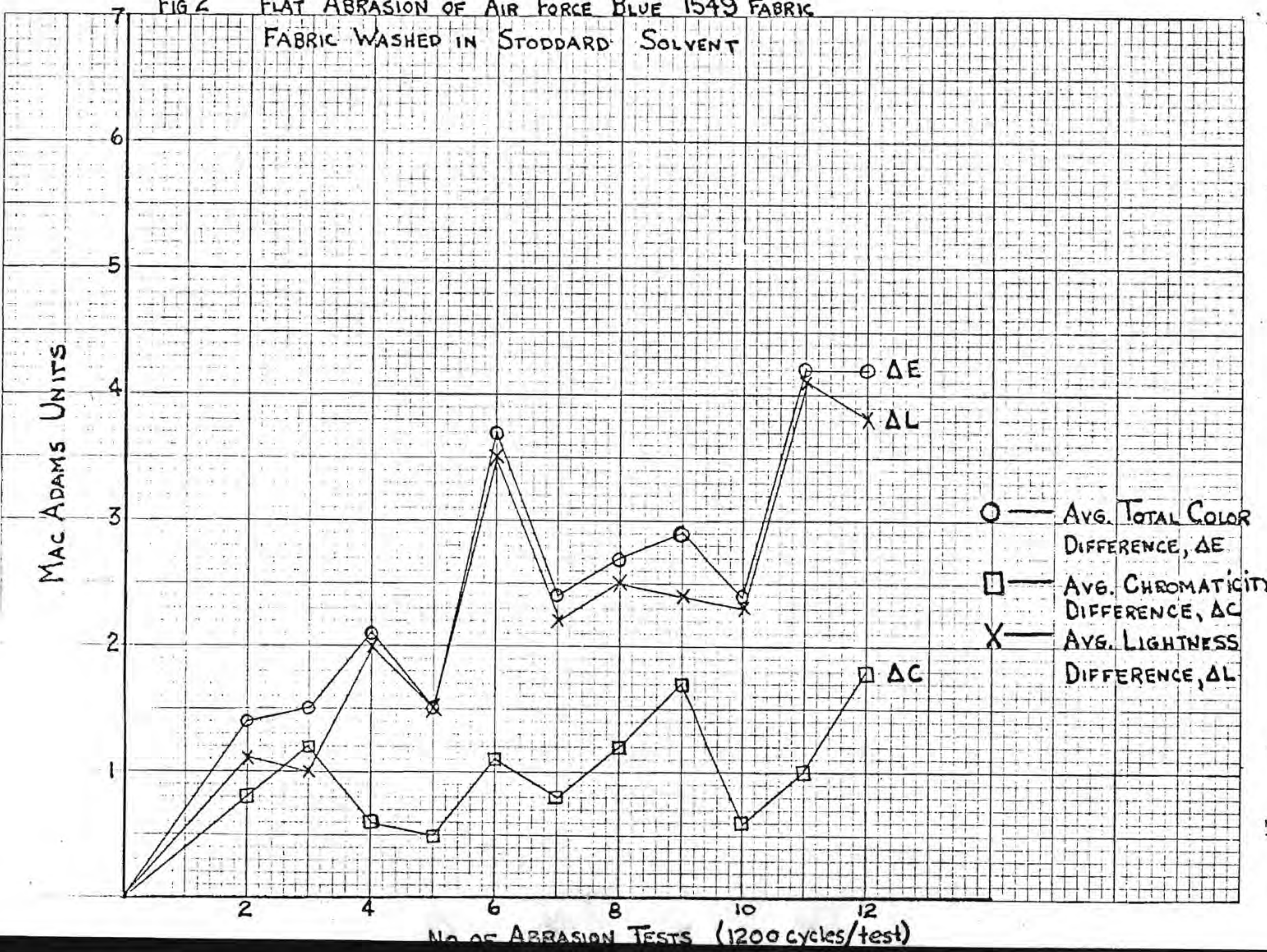


FIG 3 FLAT ABRASION OF AIR FORCE BLUE 1549 FABRIC

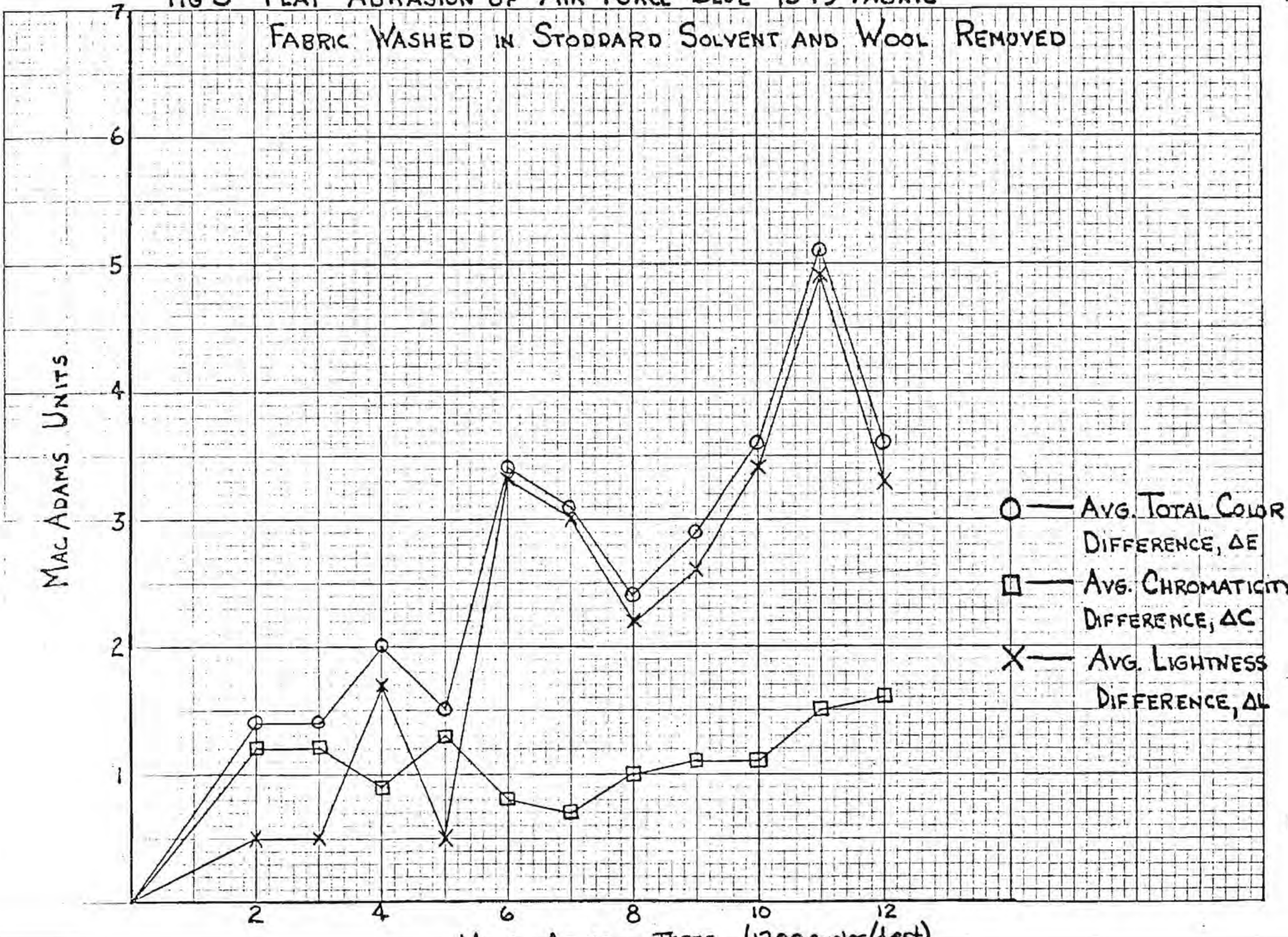
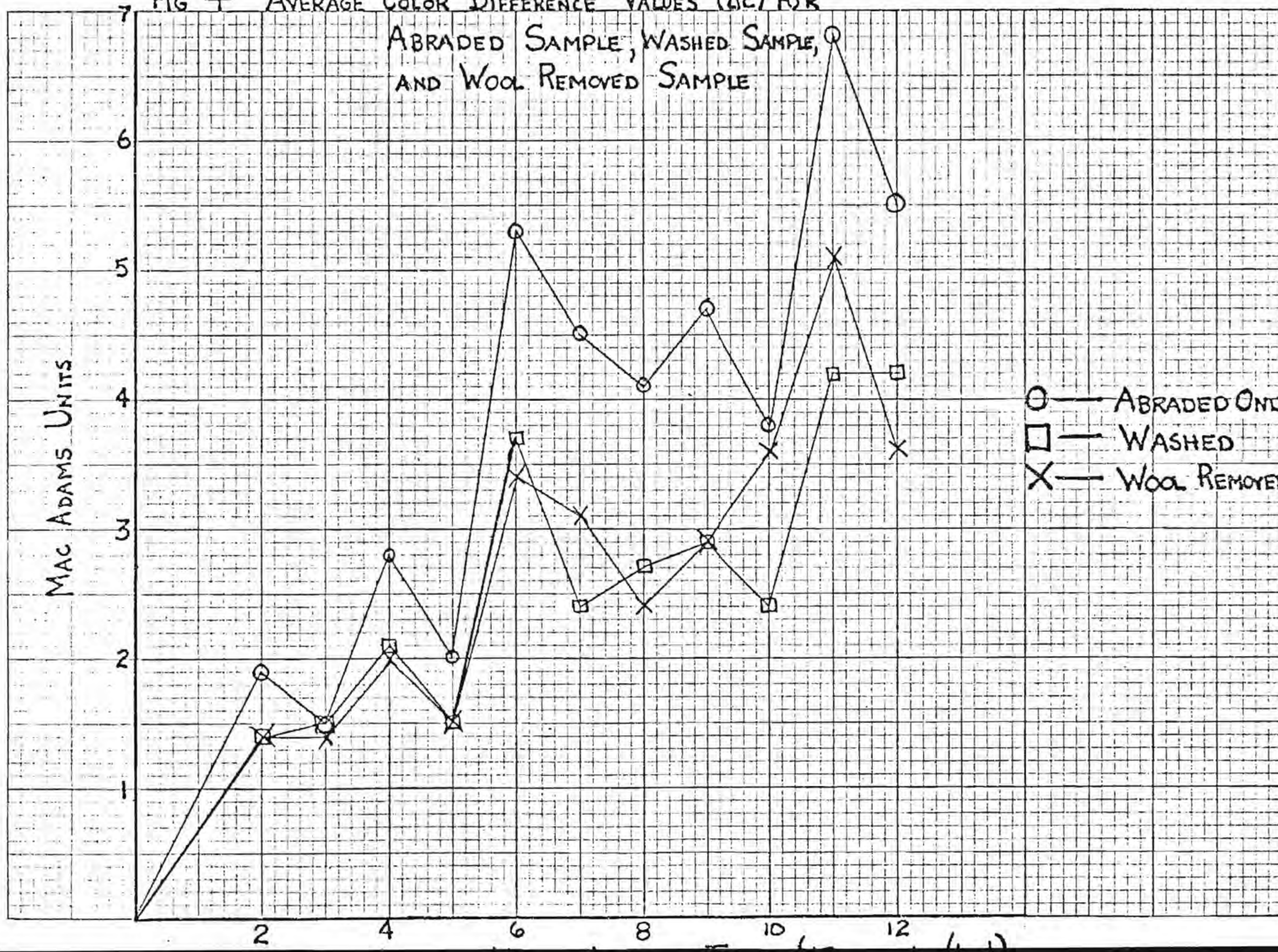


FIG 4 AVERAGE COLOR DIFFERENCE VALUES (ΔE) FOR ABRADED SAMPLE, WASHED SAMPLE, AND WOOL REMOVED SAMPLE



Trip Report

Reference: Contract No.: F 33615-72-C-1822
Project No.: E-27-613
"Exploratory Development on Polyester/Wool Uniform Fabrics
Improved Durability and Appearance."

Meeting: With representatives of E. I. duPont de Nemours and Company
Wilmington, Delaware, June 27, 1972

Purpose of Meeting: To discuss the application of duPont's polyester fibers in Air Force uniform fabrics.

Those Present: Dr. Walter C. Carter
Dr. Frank Looney
Mr. A. R. Taylor
Mr. W. G. Reynolds
Mr. W. D. Belcher
Mr. Wayne May
Mr. John F. Tirrell
Mr. Forest Benson

Details of Meeting

The primary objective of the meeting was to discover duPont's views on the problem of "frosting" in polyester/wool blends, and their recommendations with respect to means by which frosting can be minimized.

Dr. Looney described the work they had done on the worn Air Force uniform fabric, the sleeve from which we have been studying at Georgia Tech. He showed scanning electron micrographs taken of thirteen different parts of the uniform, both trousers and jacket. He also examined the specimens after wool component was removed with sodium hypochlorite. He concluded that the appearance change (i.e., the frosting) is due to the polyester component. The polyester fiber ends tend to be highly fibrillated. Also the frayed ends appear to have lost dye and the polymer looks crystalline. These conclusions are in complete agreement with our findings at Georgia Tech. It should be noted here that the wool is preferentially worn away but its removal does not lead to "frosting".

Mr. Taylor pointed out that some of the badly frosted areas in the uniform were those where the fabric was multilayered. This brought up the subject of dry cleaning solvents, dry cleaning procedures, and steam pressing since these processes can undoubtedly cause changes in the structure of the polyester fiber making it more succeptible to mechanical damage during wearing.

With respect to the choice of polyester fibers for this application, Dacron 54 was specified because of its superior durability and toughness compared with others that have been used, namely Dacron 64, Dacron 35, and Dacron 59. Dacron 54 is also a less fibrillating fiber. One problem in using Dacron 54 has been "tight ends in warping". This is probably the reason that the other Dacron fibers have seen use in this application, particularly Dacron 64. Dacron 64 is a cationic-dyeable fiber originally introduced by duPont for blends with wool on the woolen system. Dacron 35 is a pill resistant version of Dacron 54 having a lower modulus and a shorter wear life.

They concluded that if too low a fiber denier is used, the results will be pilling; if the fiber denier is increased from 3.0 to 4.5, there is an increase in the degree of frosting. They thought that a good compromise might be their 2.25 denier fiber. Mr. Reynolds, who was not present at this point in the meeting, disagrees with this suggestion due to the fact that 2.25 denier fiber would be more difficult to process.

With respect to dyeing, Mr. Taylor believes the best route to go is stock on top dyeing rather than piece dyeing. He recommended balanced primary shades for each fiber, e.g., two blues and a grey for each fiber component.

Disperse dyes should be used exclusively for the polyester fiber component. Carriers should be chosen which least affect fastness properties.

Mr. Taylor stated that, ideally, carbonizing of the fabric should be avoided since this treatment will lead to damage of both fibers. With respect to hydrolysis damage of polyester component, Dacron 64 is more easily hydrolyzed than Dacron 54. He does not believe the damage to the polyester component is severe if properly carried out.

Mr. Taylor noted that sometimes the uniform fabrics are milled; however, he stated that processes such as milling and dolly-washing leads to fabrics with improved properties.

With respect to singeing of the uniform fabric, this process should be carried out as late as possible, preceded by shearing.

Since Mr. Reynolds could not be present for the entire meeting, it was not possible to obtain his recommendations with respect to fiber processing routes. The following information was obtained from him later by telephone.

The recommended processing route is to make yarn from dyed wool top and dyed polyester top.

The polyester tow is first processed through a Pacific Converter, the cut length being 3½" or 4½" (4½" preferred). The top produced, after pin-drafting, is dyed in cans (as top sliver). After dyeing, the fiber is backwashed, an antistatic finish applied, and then dried. This dyed top is then ready for blending with the dyed wool top. The wool top is combed and then dyed, finished, and dried. The blending of the two fiber components is carried out in a two or three operations (pin-drafting or gilling). To get optimum intimacy of fiber blends, the blend is combed (French comb) followed by two additional blendings. This is followed by drawing and spinning using single creeled roving.

In addition to the comments above, it seemed to be the general concensus of opinion among those present that any yarn and fabric construction parameters or fabric processing which leads to more fiber mobility in the finished fabric will lead to an improvement in fabric frosting performance, e.g., singles rather than plied yarns, and relaxation processes such as fulling, milling, and dolly washing. In looking for ways to improve frosting performance, one must be always aware that changes in yarn and fabric construction which give better frosting performance may have adverse effects on pilling performance.

Bimonthly Status Report Number 2

(15 July to 15 September 1972)

Exploratory Development on Polyester/Wool Uniform Fabric with Improved Durability and Appearance

Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

(Prepared under Contract No. F33615-72-C-1822
by
Georgia Institute of Technology
Atlanta, Georgia 30332
W. C. Carter, Author)

Abstract

As a part of Phase I of this program, polyester fibers have been chosen for investigation to establish those properties and structural paramenters which are important in determining abrasion resistance and thus the best fiber for application in polyester/wool Air Force uniform fabrics. The basis for the selection of fibers is described in this report.

Additional work has been done to determine the nature of frosting of polyester/wool blend fabrics. When polyester/wool fabrics are abraded prior to dyeing, it is apparent from the difference in the shade of the unabraded and abraded areas, after dyeing a single fiber component of the blended fabric, that wool is preferentially worn away.

Dacron 54 and Dacron 64, two of the polyester fibers used in uniform fabrics have been shown to differ significantly in abrasion resistance. The abrasion resistance of both fibers has also been found to be altered by wet processing (extended dyeing times, excessive amounts of carrier in dyeing), Dacron 64 having poorer abrasion resistance than Dacron 54.

Dyes for application to polyester and wool have been selected, dyeings prepared, and spectrophotometric data acquired necessary for computerized color matching of the Air Force Blue Standard.

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I Introduction

In the first phase of this program, attention has been directed to gaining a comprehensive understanding of the mechanism of frosting of the polyester/wool Air Force uniform fabric. A study was made of a worn Air Force uniform and was described in the Bimonthly Status Report 1, 15 May - 15 July, 1972. It was concluded from this study as well as from a study of the flat - abrasion of the standard Air Force 1549 fabric - that there is a differential wear of the two fiber components of the blend, the frosted appearance being due to the highly fibrillated ends of the polyester component. Since both the polyester and wool fibers were found microscopically to be well penetrated by dye and dyed to an approximately solid (i.e., equivalent) shade, the frosted appearance is attributed to high light scattering by the polyester fibrils leading to an increase in the luminosity of the fabric.

The results of this work indicated that in order to improve the durability of the fabric, the most durable polyester fiber must be used. In addition, those dyeing and finishing conditions must be chosen which result in:

1. Solidity of shade (union-shade)
2. Good fiber penetration by dye
3. Minimum damage to both wool and polyester.

In this report, attention is focused on the selection of those polyester fibers to be considered for the Air Force fabric, the choice of dyes to be used to match the Air Force Blue shade, and the effect of wet processing conditions on the abrasion resistance of the blend fabric.

II Selection of Polyester Fibers

Polyester fibers are manufactured in the U.S.A. by at least ten (10) companies. Each company produces a range of chemical types as well as a range of physical types within each chemical type. The evaluation of all of these available types would be a formidable task. Therefore, if only a small number of fiber types are to be chosen for this work, some reasonable logic must be exercised in their choice. The logic is as follows:

The premise for the selection of the polyester fibers is that the polyester fiber which is best for application in uniform worsted fabrics is that fiber which has the best compromise of chemical and physical (mechanical) properties. The chemical property of prime importance is the susceptibility of the fiber to chemical damage in wet processing including dyeing, decatizing, carbonizing, etc. The physical properties include overall stress-strain behavior, abrasion resistance, crease resistance, hand, etc.

The chemical and physical properties of commercial polyester fibers are a consequence of the chemical and physical structures which are built into the fiber in the making of the polymer and its conversion to fibers. Published information is meager concerning the chemical and physical variants which are exhibited by commercial fibers. Most polyester fibers have basically the same chemical structure, namely, poly (ethyleneterephthalate); however, commercial fibers exist in which this polymer is modified. For example, the so called basic dyeable fibers are really copolymers in which a small amount of a sulfonated comonomer replaces some of the terephthalic acid in the polymerization. Other chemical modifications are those which include polymeric blocks whose structure is different from that of the poly (ethyleneterephthalate) repeating unit and polymers in which terephthalic acid is replaced by another dicarboxylic acid and/or ethylene glycol is replaced by another diol.

With respect to physical variations, the commercial polyester fibers differ in their average molecular weight and probably in their molecular distribution. In addition, variations in fiber spinning, drawing, and thermal threatments lead to fibers having differences in degree of molecular order (crystallinity, crystallite size and perfection, molecular orientation, etc.).

Thus, in view of these chemical and physical variations in structure it would not be surprising to find significant variations in fiber properties.

Based on a limited knowledge of the properties and structural parameters of commercial polyester fibers, it is proposed that the following fibers be chosen for investigation:

Dacron type 54
Dacron type 64
Dacron type 35
Dacron type 59

Although these fibers are made by one manufacturer, namely, E. I. duPont de Nemours and Company, they represent many of the variables in chemical and physical structure which should have a direct bearing on stress-strain behavior, abrasion resistance, crease recovery, etc. An extensive characterization of these fibers will be made and compared with that for other commercially available fibers.

The characterization of these fibers will include:

1. Stress-strain behavior (initial modulus, breaking extension and strength, enerby to break)

2. Fiber to fiber and fiber to metal frict on and abrasion

3. Crimp

4. Sonic modulus

5. Specific birefringence index

6. Density

7. Molecular weight (relative to each other)

Sufficient 1½ inch, 3 denier per filament, semi-dull staple will be obtained to prepare yarn and fabric for dyeing and flat abrasion studies. Once the fibers have been characterized and the fabric properites determined, it will be possible to specify those structural parameters which are important in abrasion. At this point the fiber which has optimum abrasion properties will be chosen, and other fiber manufacturers will be contacted to find out if they market fibers having similar properties. If necessary, the fibers they recommend will be similarly evaluated.

As a part of this study, it will be necessary to determine the effect of chemical processing of the abrasion properties of polyester and wool fibers. Some of this work has been done and the results of the work are reported in this report; however, fibers of comparable denier and fabrics of comparable construction were not available at this time.

Chemical and physical damage to polyester fibers results from the use of excess carrier in dyeing, excessively long dyeing cycles at elevated temperatures, and in the carbonizing of the wool component of a blend fabric. Damage should manifest itself in a decrease in abrasion resistance.

Dyeing conditions which result in both good and poor dye penetration will be used to determine the importance of dye penetration on abrasion resistance.

A similar study of wool will be made.

III Abrasion Resistance and Frosting of Polyester/Wool Fabric

A. Evidence of the Preferential Abrasion of Wool in Polyester/Wool Fabric

From examination of the worn Air Force uniform and flat abraded standard Air Force fabric, it was concluded that the wool is worn away preferentially and the frosting appearance is due primarily to the polyester component. In this work, the wet processing conditions used in making the fabrics were unkown. Therefore, to provide more positive evidence, an unscoured, undyed Dacron 54/wool fabric was abraded prior to dyeing. In this way, the effect of wet processing on abrasion was eliminated. The fabric was abraded for 3600 cycles using the Stoll Universal Wear Tester. One of the abraded fabrics was dyed, with a disperse dye, Latyl Blue LS. Under the dyeing conditions used, the polyester component was well-dyed and the wool component was only slightly stained. A second abraded fabric was dyed with a chrome dye, Acid Chrome Blue RRA. Only the wool component dyed. The abraded areas of the fabric dyed with the disperse dye was darker than that of the unabraded area, whereas, the reverse was found for the fabric dyed with the chrome dye. These results are consistent with the previous conclusion that wool is preferentially worn away.

B. Abrasion of Dacron 54 versus Dacron 64

In order to gain some preliminary results on the abrasion of commercial polyester fibers and wool, worsted-like fabrics of Dacron 54, Dacron 64, and wool were purchased from Testfabrics, Inc. These fabrics were dyed with appropriate dyes and then abraded. The wool fabric exhibited very poor abrasion resistance due probably to the fact that it had been bleached and therefore chemically damaged. The polyester fabric had much better abrasion resistance, Dacron 54 being better than Dacron 64, although the Dacron 54 fabric pilled more than the Dacron 64. The Dacron 54 fiber was $\sim$ 1.5 denier and Dacron 64 $\sim$ 2.5 denier. This difference in fiber denier as well as a difference in fabric construction accounts in part for the observed results.

Dyeing conditions were varied to show the effect of prolonged dyeing times and excess carrier on abrasion resistance. It was discovered that the abrasion resistance decreased with an increase in the time of dyeing and the amount of carrier used. In all cases, Dacron 64 had poorer abrasion resistance that Dacron 54.

C. Single Filament Abrasion of Polyester Fiber

Single filaments of Dacron 54 and Dacron 64 (3 denier per filament) were abraded against a tungsten wire ($\sim$ 8 mil diameter) under a normal load of 3 grams for Dacron 64 and 4 grams for Dacron 54. After various times of abrasion, the friction of the abraded surface against a stainless steel wire (50 mg normal load) was determined. Scanning electron micrographs were also made of the abraded fibers. The following conclusion are drawn from this work:

1. The abrasion resistance of Dacron 64 is poorer that that of Dacron 54. (Dacron 64 will not withstand abrasion when the load normal to the fiber is 4 grams.)

2. There is evidence of fibrillation damage of both fibers; however, the character of the fibrillation is different for the two fibers. Small fibrils are produced in both cases, whereas, long longitudinal cracks are noted primarily for Dacron 64 which become very evident when the fiber fails.

3. The friction of the fibers against stainless steel increases with the time of abrasion with little difference between the two fibers.

IV Examination of Current Practice in the Manufacture of Polyester/Wool Air Force Blue 1549 Fabric

To establish current practice with respect to the mechanism of frosting and processing procedures for polyester/wool blends, polyester fiber producers, dye-stuff manufactureres, and textile firms who produce polyester/wool worsted uniform fabrics were contacted. As far as the mechanism of frosting is concerned no new insight has been gained from the fiber producers other than that described previously. None of the fiber producers have made a positive recommendation with respect to the choice of polyester fiber with the possible exception of E. I. duPont.

Approximately eight (8) dyestuff manufacturers have been contacted and have responded. They have been most helpful, supplying recommended dyes for both fibers, dyeing procedures, dye formulation for both fibers and spectrophotometric curves for their recommended dyes.

Two textile firms have been contacted with the intention of contracting with them to supply important textile processing details necessary for the success of the project. These firms were J. P. Stevens and Burlington Industries. At this time, their representative has shown little interest in cooperating.

V Selection of Dyes, Dye Formulations, and Dyeing Procedures

A. Selection of Dyes

Samples of all dyes recommended by dye manufacturers have been obtained. The recommended disperse dyes have been applied to Dacron 54 and Dacron 64 and the acid and chrome dyes to wool. Shade cards for each dye have been made and spectrophotometric curves established.

B. Dye Formulations to Match Air Force Standard

Preliminary dyeing on polyester/wool fabrics based on computed shade matches have been made. The resulting dyeings gave a close match to the standard; however, the two fiber components were not identical in shade, the polyester component being lighter than the wool component.

The spectrophotometric curves established for each dye will be used along with a color matching computer program available to Georgia Tech to establish the most economical shade matches consistent with good fastness properties.

C. Stock-Dyeing versus Piece Dyeing

Dye manufacturers as well as fiber producers generally recommend stock dyeing of wool and polyester for the production of the Air Force fabric rather than piece dyeing. Experience at Georgia Tech indicates the reasons for this preference:

1. Better control of color match with stock or top dyed fibers.

2. No staining of wool by disperse dyes in stock dyeing.

3. In stock or top dyeing the problem of poor dye penetration encountered in dyeing the high density worsted fabric is avoided.

D. Analysis of Shade Standard

A detailed analysis has been made of the report prepared by J. P. Stevens and Company, Inc., under Contract No. AF 33(657)-16558 entitled "Development of Shade Standard and Shade Tolerance in Blue 1549 Wool/Polyester Cloth, Stock Dyed Conforming to Type 111 of Specification MIL-C-21115B". This analysis consisted primarily of an examination of spectrophotometric data supplied in the report. The following conclusions are drawn:

1. Although shade tolerance levels were established by Stevens, they are not considered realistic, being so small (less than one (1) MacAdam color difference unit) that one could easily attribute the tolerance levels to random instrumental errors in the making of spectrophotometric measurements. In addition, there were inconsistencies in the data. For esample, a full red is actually lighter than a thin red based on the data supplied.

2. The color standard supplied by the Air Force to J. P. Stevens, as well as the color standard established by J. P. Stevens is radically different from the color standard supplied to Georgia Tech as part of this contract, being much lighter than the standard supplied to Georgia Tech. Evidently, more than one blue shade has been standard for uniforms.

VI Future Work

The work during the next bimonthly period will include:

A. The characterization of polyester fibers chosen for this program as described in this report, their conversion to yarns and fabrics, and an evaluation of their abrasion resistance.

B. The establishment of the best dyeing procedures fo wool and polyester fibers which have the least detrimental effect on abrasion resistance.

E-27-413

Bimonthly Technical Report Number 3

(15 November 1972 to 15 January 1973)

Exploratory Development on Polyester/Wool

Uniform Fabric with Improved Durability and Appearance

Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

(Prepared under Contract No. F33615-72-C-1822

by Georgia Institute of Technology, Atlanta, Georgia,

W. C. Carter, author)

Abstract

The single fiber abrasion behavior of Dacron 35, 54, 59, and 64 has been investigated. An attempt has been made to relate mechanical properties to abrasion resistance with little success; although the energy to rupture must be involved in abrasion resistance, it appears that other factors are involved, e.g., the energy to yield appears to be related to abrasion resistance. Tests to determine the mechanical properties and abrasion resistance of the polyester fibers after dyeing are being performed. Changes in properties occur as a result of dyeing. This means that the fiber properties important in abrasion are those for the dyed rather than the undyed fiber. As a result of the work to determine the mechanical properties after dyeing and dye depth, a preferred pressure dyeing procedure for the polyester component has been established.

Included in this report is the design of a fractional factorial experiment which will allow the sorting out of the effects of selected processing variables on the abrasion resistance of polyester/wool blend fabrics. Also listed in this report are those companies who have been contacted in an attempt to have the fabrics required for the fractional factorial experiment produced.

TABLE OF CONTENTS

I. Introduction

The characterization of the mechanical properties of the polyester fibers chosen for this study were described in the Interim Technical Report Number 1 (30 November, 1972). The fibers included Dacron 35, 54, 59, and 64. This report includes further characterization of these fibers:

1. Single filament abrasion
2. Effect of dyeing conditions on mechanical properties of fiber
3. Effect of dyeing conditions on color yield

As a result of work done to date, an experiment has been designed to delineate the effects of the variables considered important in the abrasion of polyester/wool uniform fabrics. The experimental design is described in this report.

II. Single Filament Abrasion

A fatigue apparatus capable of abrading single fibers under normal loads approximating those involved in standard flat-abrasion tests and speeds up to 1800 cycles per minute has been used to assess the relative abrasion resistance of the four polyester fibers selected for this study. Single, three denier, filaments of Dacron 35, 54, 59, and 64 have been abraded against tungsten wire ($\sim$8 mil. diameter); the load normal to the fibers being 200 mg. The filaments were abraded from one to ten hours (30 cycles/sec.) and then examined by scanning electron and light microscopy. Noticeable damage to all fibers was obtained after only one hour of abrasion. Although the amount of damage to the fibers increased with an increase in the time of abrasion, the damage after ten hours was not as great as would be expected considering the damage after one hour. This is probably due to a decrease in the pressure applied to the filament by the abrading wire. An increase in contact surface as fiber damage occurs has been observed and thus, a decrease in force per unit area exerted on the filament by the abrading wire would be expected.

From this study, it is concluded that the decreasing order of abrasion resistance is Dacron 35 $>$ Dacron 54 $>$ Dacron 59 $\gg$ Dacron 64. Dacron 64 appears to have much poorer abrasion resistance than the other fibers. Dacron 35 and Dacron 54 are similar in their abrasion resistance. Attempts have been made to relate the abrasion behavior to mechanical properties, primarily initial modulus and energy to break. There is no clear relationship; however, the order of abrasion resistance does correlate with the energy to yield, decreasing as the energy to yield decreases. The very low energy to break for Dacron 64 probably accounts for its poor abrasion resistance; however, other structural parameters including polymer molecular weight, degree of crystallinity, and molecular orientation, must be involved to explain the differences in abrasion exhibited by Dacron 35, Dacron 54, and Dacron 59. As will be described in this report, characterization data obtained for undyed, unfinished fiber may, indeed, relate poorly to end use abrasion behavior since the structure and properties of the fibers change as a result of the dyeing and other processing steps. Therefore, dyed fibers will be abraded and related to other properties of the dyed fibers.

III. Effect of Dyeing on Mechanical Properties of Polyester Fibers

Two polyester fibers were chosen for this work: Dacron 54 and Dacron 64. Both of these fibers have been used widely in the production of polyester/wool worsted fabrics, and, they differ considerably in their abrasion resistance, Dacron 64 being less abrasion resistant. Common commercial practice in the dyeing of polyester is either to dye at $\sim 100^{\circ}$ C in the presence of dye carrier (8-10 per cent based on fiber weight) or under pressure with a small amount of carrier (~ 3 per cent based on fiber weight). Since carriers have a plasticizing action on the fiber, it would be expected that some deleterious changes in abrasion properties would result from their use. Therefore, a study has been made of the effect of dyeing conditions on color yield, and mechanical properties. The variables included were as follows:

1. dyeing temperature, 120°, 125°, 135° C
2. concentration of Na_2SO_4, 0.0, 5.0 g/1
3. dyeing time, 30, 60, 90 minutes
4. carrier concentration, 0.0, 3.0% based on fiber weight

Within the limits of the variables studied the following conclusions can be drawn:

1. The presence of carrier does not alter the breaking strength; however, all dyeing conditions lead to a decrease in the elongation to break, the decrease being greater for Dacron 64.
2. All conditons of dyeing lead to a decrease in the work to rupture, approximately 30 per cent for Dacron 54, and approximately 40 per cent for Dacron 64.
3. There is a small increase in the modulus (initial) of Dacron 64 due to dyeing but no change in the modulus of Dacron 54.

4. The presence of Na_2SO_4 does not alter the stress strain behavior.
5. Only in the case of Dacron 64 dyed at 135° C is there evidence that there is a decrease in energy to rupture with increasing time of dyeing at a given temperature.

From the changes in dye depth as well as the changes in mechanical behavior as functions of dyeing conditions, it is concluded that, for pressure dyeing, the preferred dyeing conditions for both fibers are:

125° C
3.0% carrier (based on fiber weight)
Liquor Ratio 10:1
Dyeing time, 60 minutes

IV. Design of Experiment to Delineate Effects of Variables in the Composition and Structure of Polyester/Wool Fabrics on Abrasion Resistance

The design of an experiment to sort out the effect of variables in the production of polyester/wool uniform fabrics abrasion resistance is based on information obtained from several sources:

1. Discussions with fiber and textile manufacturers, as well as manufacturers of dyes and dyeing assistants
2. Technical information available from fiber manufacturers
3. Literature in technical journals related to fiber and fabric abrasion (pilling and frosting)
4. Work conducted in this program

It is concluded that the variables which should be investigated in a statistically designed experiment are as follows:

1. Polyester type
2. Grade of wool
3. Relative amounts of wool and polyester in blend
4. Yarn twist
5. Combing
6. Denier of polyester

To minimize the number of fabrics required for this experiment, it was decided that the basic design would be a 2^5 design, the five variables being the first five listed above at two levels for each variable. A fractional factorial experiment (5 factors in 8 observations) will be performed, i.e. eight (8) fabrics. The production of four additional fabrics will make possible an evaluation of an additional level for variable 1 (polyester type) and variable 4 (yarn twist) as well as an evaluation of the effect of the denier of the polyester fiber on abrasion.

The variables and levels for each variable arranged in decreasing order of their estimated importance in abrasion are as follows.

	Variable	Level -	Level +
A.	Polyester Type (3 denier)	Dacron 64	Dacron 54
B.	Grade of Wool (Domestic)	64's	64-70's
C.	Composition of Blend Polyester/Wool	60/40	40/60
D.	Yarn Twist (t.p.i.)	12	15
E.	Combing of Blended Top	yes	no

The experiments to be performed are described below:

Fractional Factorial for 2^5 Design (¼ replicate)

EQUATE D to ABC
E to -BC

	A	B	C	D	E	Treat. Comb.
Y_1	-	-	-	-	-	1
Y_2	+	-	-	+	-	ad
Y_3	-	+	-	+	+	bde
Y_4	+	+	-	-	+	abe
Y_5	-	-	+	+	+	cde
Y_6	+	-	+	-	+	ace
Y_7	-	+	+	-	-	bc
Y_8	+	+	+	+	-	abcd

Effects and Aliases
A, -DE
B, -CE
C, -BE
D, -AE
E, -BC, -AD
AB, CD
AC, BD

$D(D=ABC) = (D^2=ABCD) = (I=ABCD)$

$E(E=-BC) = (E^2=-BCE) = (I=-BCE)$

$(ABCD)(-BCE) = -ADE$

defining contrasts I, ABCD, -BCE, -ADE

aliases - (i) A, BCD, -ACE, -DE

(ii) B, ACD, -CE, -ABDE

(iii) C, ABD, -BE, -ACDE

(iv) D, ABC, -BCDE, -AF

(v) E, ABCDE, -BC, -AD

(vi) AB, CD, -ACE, -BDE

(vii) AC, BD, -ABE, -CDE

To obtain additional information, a fabric will be made using 4.5 denier Dacron 54 to demonstrate the effect of denier on abrasion resistance. A third twist level (8 tpi) will also be included. Dacron 35 will be substituted in treatment combination 1 since Dacron 35 has been shown to have slightly better abrasion resistance than Dacron 54. Dacron 64 is included in the basic design since a substantial amount of this fiber is being used in this application even though its abrasion resistance is poorer than that of the other polyester fibers studied.

The experimental plan is to prepare about 20 yards of each fabric, 5 yards of each to be supplied to the Air Force Materials Laboratory.

V. Obtaining of Services to Produce Experimental Fabrics

Considerable effort has been made to obtain the services necessary to produce the experimental fabrics described in IV above. The services required are:

1. Conversion of polyester tow to top (Pacific convertor)
2. Dyeing of wool and polyester top
3. Recombing of dyed wool top
4. Blending of dyed wool top and dyed polyester top
5. Conversion of blended top to yarn
6. Conversion of yarn to fabric
7. Finishing of fabric

All of these operations require commercial size equipment. Only the largest textile manufacturers have facilities for carrying out all of these operations, for example, Burlington!! Therefore, it is necessary to obtain the services of several companies. The companies contacted are as follows:

1. Wellman, Inc., Johnsonville, South Carolina
2. Southern Worsted Mills, Inc., Greenville, South Carolina
3. Model Dye, Sumter, South Carolina
4. Ames Textile Corporation, Lowell, Massachusetts
5. Stillwater, Inc., Goshen, Virginia
6. Textile Research Service, Raleigh, North Carolina
7. Riverside Mills, Augusta, Georgia
8. M. Dursin and Sons, Woonsocket, Rhode Island

The response to our requests for assistance has been generally negative:

a. "getting out of polyester/wool worsted business"
b. "too busy" to give assistance
c. We do not represent a "potential customer"

Present Status:

1. Wellman, Inc., can supply wool and polyester tops
2. No dyer has been obtained
3. Wellman will blend the wool and polyester tops
4. Westbrook Spinning is being contacted for making of yarn
5. Textile Research Services will produce fabrics
6. Stillwater will finish fabrics

Bimonthly Technical Report Number 4

(15 January 1973 to 15 March 1973)

Exploratory Development on Polyester/Wool Uniform Fabric with Improved Durability and Appearance

Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

(Prepared under Contract No. F33615-72-C-1822 by
Georgia Institute of Technology, Atlanta, Georgia,
A. J. Maguire and W. C. Carter, authors)

Abstract

An experimental program to determine the effects of fabric composition and structure on its wearing qualities is described. The production of twelve (12) experimental fabrics required by this program is in progress. It is estimated that 10-12 weeks will be required for the production of these fabrics.

The effects of the dyeing conditions used in dyeing polyester fibers on color yield and abrasion properties have been established for Dacron 54 and Dacron 64. Optimum dyeing procedures under atmospheric conditions (95-100°C) and under pressure (120-135°C) have been established for these two polyester fibers. The screening of disperse dyes for application to polyester fibers has been completed.

Table of Contents

I. Introduction

The design of an experiment to sort out the effect of variables in the production of polyester/wool uniform fabrics on their abrasion resistance was described in the Bimonthly Technical Report No. 3 for the period 15 November 1972 to 15 January 1973. The difficulties encountered in obtaining the outside services necessary for the production of sample fabrics required by the experiment were also described. These problems have now been solved as described in this report.

Since the mechanical properties and abrasion behavior of polyester and wool fibers can be altered by the dyeing procedures used, additional work to establish the effects of dyeing conditions (dyeing temperature, dyeing time, amount of carrier) on color yield, tensile properties, and abrasion has been carried out.

II. Design of Experiment to Delineate Effects of Variables in the Composition and Structure of Polyester/Wool Fabrics on Abrasion Resistance

The design of an experiment to sort out the effect of variables in the production of polyester/wool uniform fabrics on abrasion resistance was described previously.[1] After consultation with very knowledgeable people in the worsted field, particularly yarn spinners, the previous experimental design has been altered. The major changes are as follows:

1. The variable of the combing of the blended tops has been deleted since combing is demanded for the production of uniform yarns. This variable has been replaced by the variable of "carbonizing", i.e., experimental fabrics Y_1, Y_2, Y_3, and Y_4 will be carbonized to remove vegetable matter and the remaining fabrics will not be carbonized. This variable was chosen because some firms carbonize worsted fabrics and others do not depending on the quality of wool being used. Carbonizing leads to the damage of both polyester and wool fibers.
2. The twist levels to be employed in the experimental design were 12 and 15 tpi. A third twist level of 8 tpi was indicated previously. This has been changed to 18 tpi due to the difficulty of producing a satisfactory yarn with 8 tpi.
3. The experimental plan now calls for 50 yards of each fabric, 5 yards of each to be supplied to the Air Force Materials Laboratory.

The final form of the experimental plan which is now "in the works" is shown on the following page.

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[1] Bimonthly Technical Report No. 3, 15 November 1972 to 15 January 1973.

The variables and levels for each variable arranged in decreasing order of their estimated importance in abrasion are as follows.

	Variable	Level -	Level +
A.	Polyester Type (3 denier)	Dacron 64	Dacron 54
B.	Grade of Wool (Domestic)	64's	64-70's
C.	Carbonizing	yes	no
D.	Composition of Blend - Polyester/Wool	60/40	40/60
E.	Yarn Twist (t.p.i.)	12	15

The experiments to be performed are described below:

Fractional Factorial for 2^5 Design (½ replicate)

EQUATE D to ABC
E to -BC

	A	B	C	D	E	Treat. Comb.	Effects and Aliases
Y_1	-	-	-	-	-	1	A, -DE
Y_2	+	-	-	+	-	ad	B, -CE
Y_3	-	+	-	+	+	bde	C, -BE
Y_4	+	+	-	-	+	abe	D, -AE
Y_5	-	-	+	+	+	cde	E, -BC, -AD
Y_6	+	-	+	-	+	ace	AB, CD
Y_7	-	+	+	-	-	bc	AC, BD
Y_8	+	+	+	+	-	abcd	

$D(D=ABC) = (D^2=ABCD) = (I=ABCD)$

$E(E=-BC) = (E^2=-BCE) = (I=-BCE)$

$(ABCD)(-BCE) = -ADE$

defining contrasts I, ABCD, -BCE, -ADE

aliases - (i) A, BCD, -ACE, -DE
(ii) B, ACD, -CE, -ABDE
(iii) C, ABD, -BE, -ACDE
(iv) D, ABC, -BCDE, -AF
(v) E, ABCDE, -BC, -AD
(vi) AB, CD, -ACE, -BDE
(vii) AC, BD, -ABE, -CDE

Notes:

1. In order to obtain additional information concerning the effect of yarn twist, the composition corresponding to Y_6 in the design will be converted to two additional fabrics in which the yarn twist will be 12 tpi and 18 tpi.

2. In order to determine the effect of polyester denier, an additional fabric will be prepared in which a 4.5 denier Dacron 54 will replace the 3.0 denier Dacron 54 in the sample described as Y_6 .

3. It would be desirable to evaluate another polyester fiber, whose properties differ from those of Dacron 54 and Dacron 64. To accomplish this, a fabric sample will be prepared in which 3.0 denier Dacron 35 replaces the 3.0 denier Dacron 54 in the sample described as Y_6.

In summary, ten different blended polyester/wool tops will be prepared from which twelve sample fabrics will be made. Flow diagrams for the production of the sample fabrics are shown in Figs. 1, 2, 3.

The companies who will supply the necessary services for producing the sample fabrics are as follows:

1. Source of wool tops and polyester tops:

   Wellman, Incorporated
   Johnsonville, South Carolina

2. Dyeing and blending of dyed tops:

   Florence Dye Works
   Woonsocket, Rhode Island

3. Spinning of yarns from dyed and blended tops:

   Westbrook Spinning Company
   Westbrook, Maine

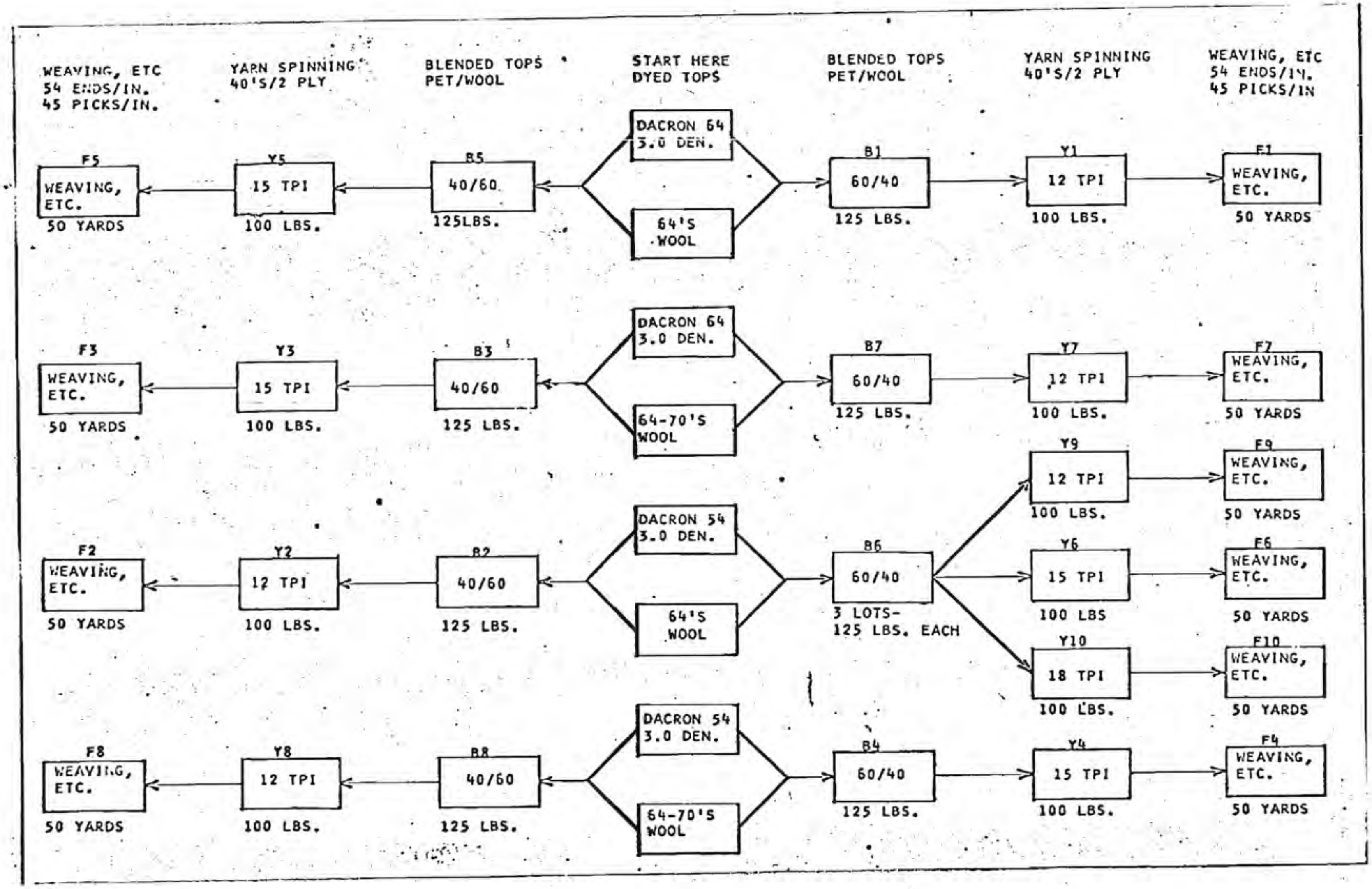

WEAVING, ETC
54 ENDS/IN.
45 PICKS/IN.
YARN SPINNING
40'S/2 PLY
BLENDED TOPS
PET/WOOL
START HERE
DYED TOPS
BLENDED TOPS
PET/WOOL
YARN SPINNING
40'S/2 PLY
WEAVING, ETC
54 ENDS/IN.
45 PICKS/IN
F5
WEAVING, ETC.
50 YARDS
Y5
15 TPI
100 LBS.
B5
40/60
125LBS.
DACRON 64
3.0 DEN.
64'S WOOL
B1
60/40
125 LBS.
Y1
12 TPI
100 LBS.
F1
WEAVING, ETC.
50 YARDS
F3
WEAVING, ETC.
50 YARDS
Y3
15 TPI
100 LBS.
B3
40/60
125 LBS.
DACRON 64
3.0 DEN.
64-70'S WOOL
B7
60/40
125 LBS.
Y7
12 TPI
100 LBS.
F7
WEAVING, ETC.
50 YARDS
Y9
12 TPI
100 LBS.
F9
WEAVING, ETC.
50 YARDS
F2
WEAVING, ETC.
50 YARDS
Y2
12 TPI
100 LBS.
B2
40/60
125 LBS.
DACRON 54
3.0 DEN.
64'S WOOL
B6
60/40
3 LOTS-
125 LBS. EACH
Y6
15 TPI
100 LBS
F6
WEAVING, ETC.
50 YARDS
Y10
18 TPI
100 LBS.
F10
WEAVING, ETC.
50 YARDS
F8
WEAVING, ETC.
50 YARDS
Y8
12 TPI
100 LBS.
B8
40/60
125 LBS.
DACRON 54
3.0 DEN.
64-70'S WOOL
B4
60/40
125 LBS.
Y4
15 TPI
100 LBS.
F4
WEAVING, ETC.
50 YARDS

FIGURE 1

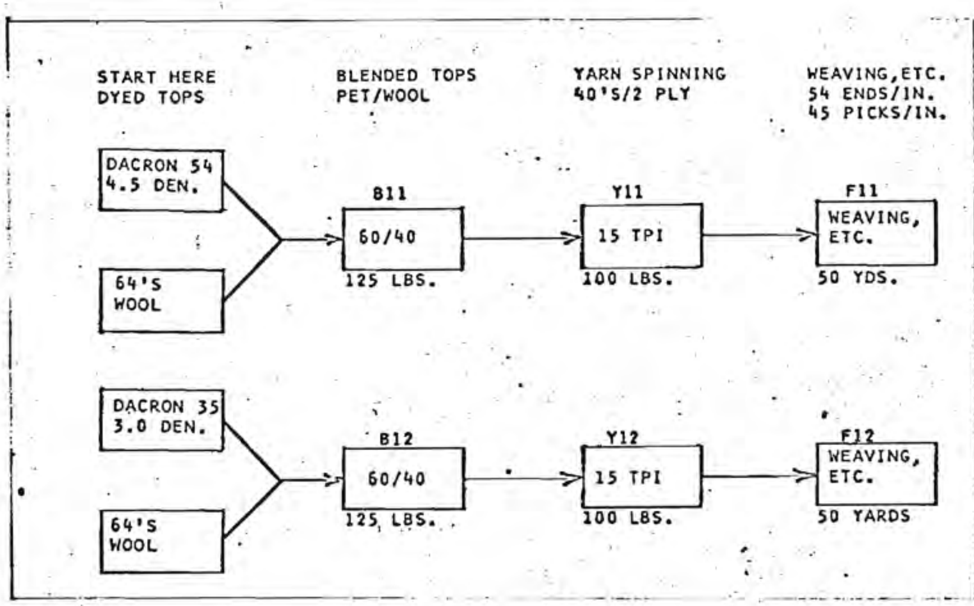

START HERE
DYED TOPS
BLENDED TOPS
PET/WOOL
YARN SPINNING
40'S/2 PLY
WEAVING,ETC.
54 ENDS/IN.
45 PICKS/IN.
DACRON 54
4.5 DEN.
64'S
WOOL
B11
60/40
125 LBS.
Y11
15 TPI
100 LBS.
F11
WEAVING,
ETC.
50 YDS.
DACRON 35
3.0 DEN.
64'S
WOOL
B12
60/40
125 LBS.
Y12
15 TPI
100 LBS.
F12
WEAVING,
ETC.
50 YARDS

FIGURE 2

Fabrics

F1
F2
F3
F4

$\rightarrow$ Carbonized

F5
F6
F7
F8
F9
F10
F11
F12

$\rightarrow$ Finishing will be same for all fabrics after fabrics F1, F2, F3, and F4 have been carbonized, i.e., standard finishing for tropical worsted uniform fabrics.

FIGURE 3

4. Weaving:

   Textile Research Services
   Raleigh, North Carolina

5. Finishing of fabrics:

   Florence Finishing Company
   Woonsocket, Rhode Island

III. Effect of Dyeing Conditions on the Color Yield and Abrasion Properties of Polyester Fibers

A. Dyeing Conditions and Color Yield

In the dyeing of polyester fibers, two alternative dyeing procedures are usually employed:

1. Atmospheric dyeing at a temperature of approximately 100°C with the use of dyeing "carriers" in amounts from 10 to 15 percent based on the weight of fiber to be dyed.
2. Pressure dyeing at a temperature of 120° to 135°C either with no dyeing carrier or approximately 3 percent based on the weight of fiber to be dyed.

The latter procedure is preferred because of shorter dyeing cycles but there is the requirement of dyeing equipment which can be pressurized. Many dyehouses do not possess this equipment. The variables which affect color yields and mechanical properties are the dyeing temperature, dyeing time, and the amount of carrier used, deterioration in polyester fiber properties increasing with increases in each of these variables.

B. Effect of Dyeing Conditions on Color Yields

In this study, a disperse dye typical of the blue component in the Air Force Blue 1549 shade, namely Latyl Blue LS, was chosen. The assumption is that the other dyes necessary for producing the Air Force shade will behave similarly.

The following conditions were used:

1. Atmospheric dyeing

Temperature °C	95°, 100°
% Carrier (based on fiber weight)	9.0, 10.0, 11.0
Dyeing time (min.)	60, 120, 150

2. Pressure dyeing

Temperature ^{o}C	120^{o}, 125^{o}, 135^{o}
% Carrier (based on fiber weight)	0.0, 3.0
Dyeing time (min.)	30, 60, 90

The carrier used in these dyeings is Cindye DAC-888, a butylbenzoate carrier sold by Cindet Chemicals, Inc., and recommended for both atmospheric and pressure dyeing of polyester fibers. A typical dyeing rate curve using this carrier is shown in Fig. 4.

C. Dyeing Results

1. Pressure dyeing

The variation in color yield with variations in dyeing time, dyeing temperature and carrier is shown in Fig. 5. Total lightness difference (ΔL), expressed in MacAdams units, is plotted in Fig. 5 since any color differences are due primarily to lightness differences. All dyeings are compared with a standard dyeing, namely, $125^{o}C$, 60 min., 3.0% carrier. This standard reference was chosen since previous work had shown that the physical properties including breaking elongation, breaking strength, initial modulus and work to rupture and recently, abrasion resistance were adversely affected when a dyeing temperature of $135^{o}C$ is used. Fig. 5 shows clearly that the effect of time and temperature of dyeing on color yields is much smaller in the presence of carrier than when no carrier is used. Therefore, for pressure dyeing the following alternate procedures are recommended:

a. 3.0% carrier (DAC-888)
   120^{o} C
   90 min.

b. 3.0% carrier (DAC-888)
   125^{o} C
   60 min.

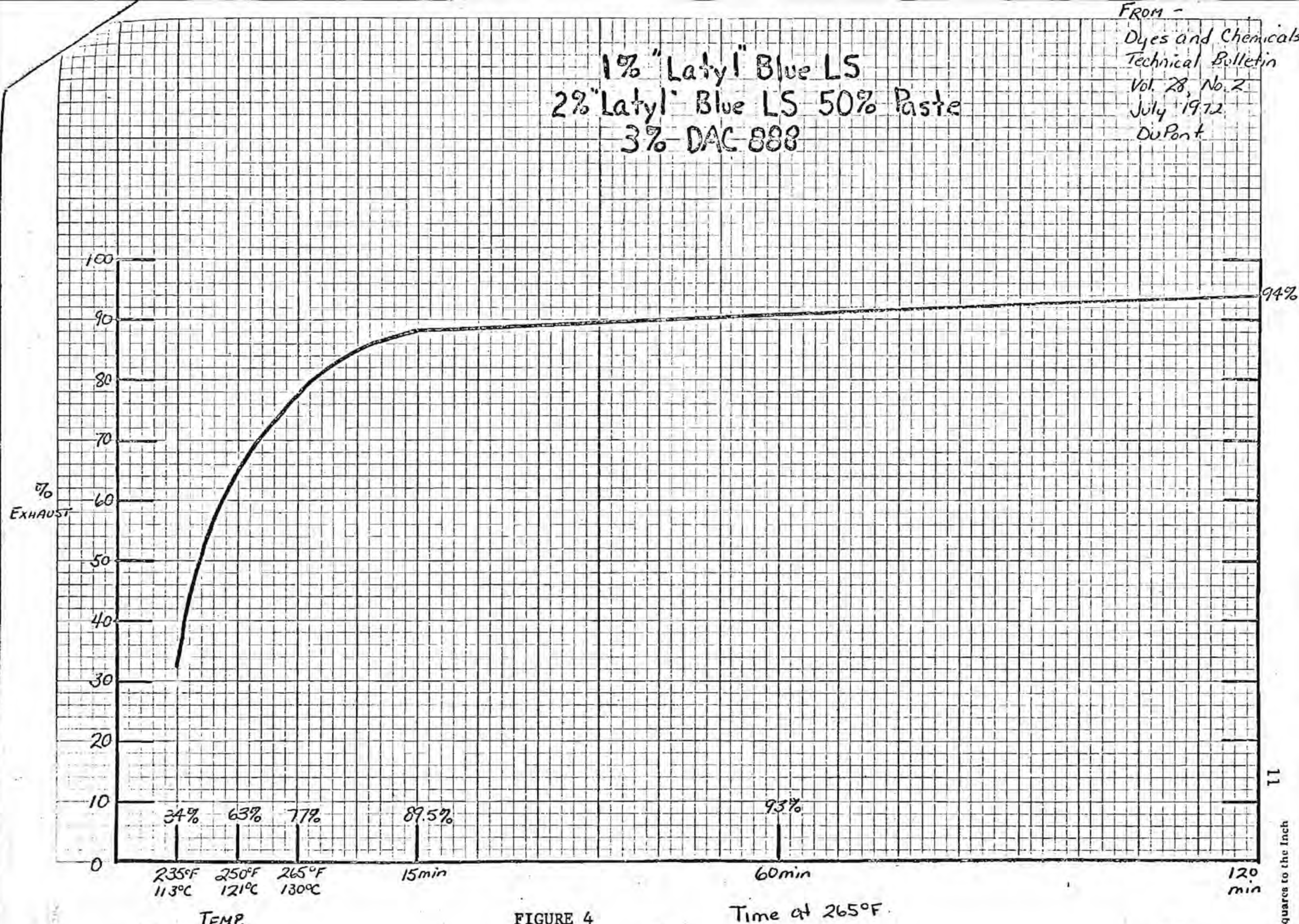
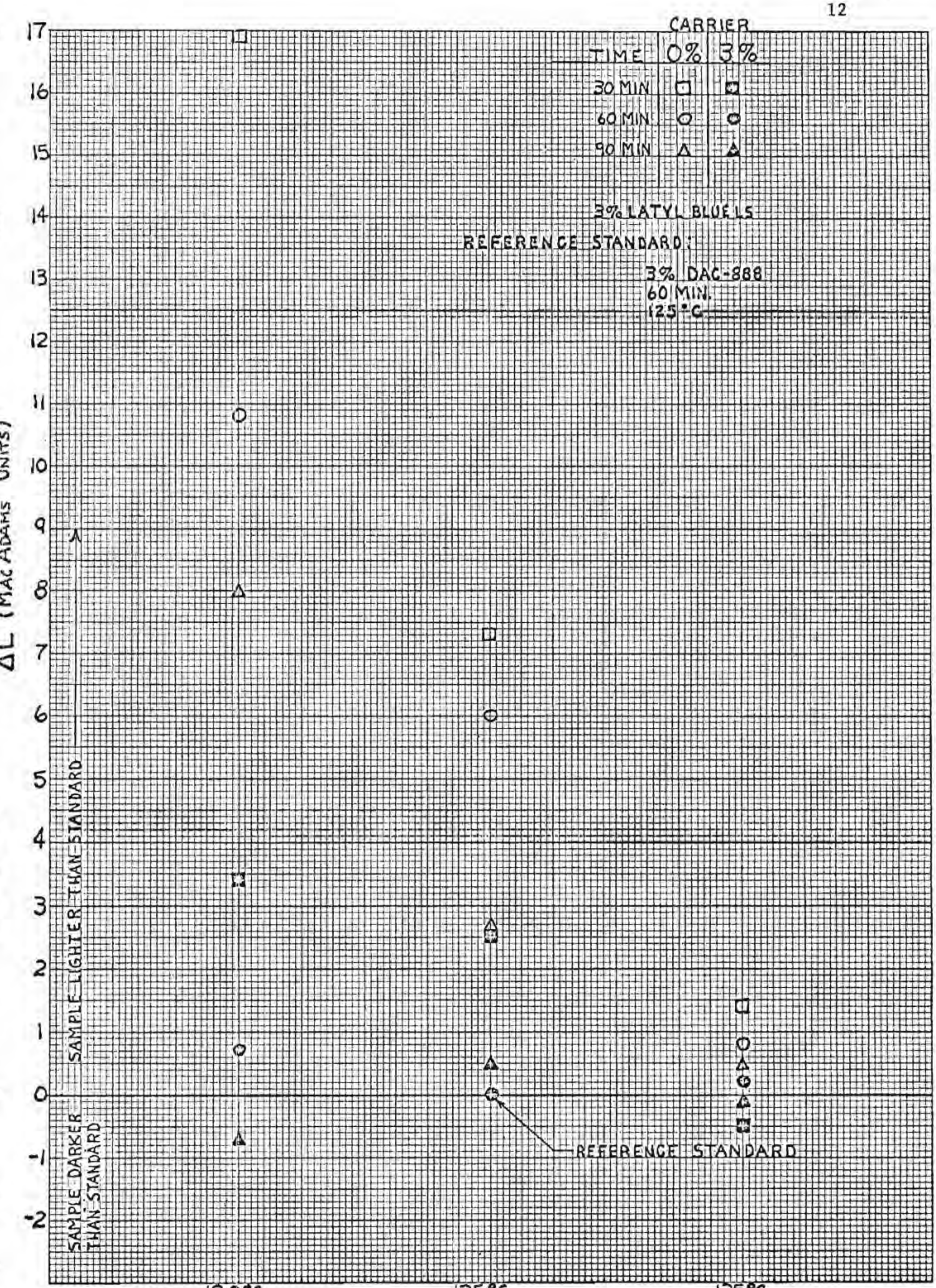


FIGURE 4

10 Squares to the Inch



CARRIER
TIME
0%
3%
30 MIN
60 MIN
90 MIN
3% LATYL BLUE LS
REFERENCE STANDARD:
3% DAC-888
60 MIN.
125°C
ΔL (MAC ADAMS UNITS)
SAMPLE LIGHTER THAN STANDARD
SAMPLE DARKER THAN STANDARD
REFERENCE STANDARD
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
120°C
125°C
135°C

FIGURE 5

2. Atmospheric dyeing

For dyeings made at 95° and 100°C, the reference dyeing to establish the effect of carrier, temperature and time of dyeing on color yields, was 100°C, 10% carrier, 120 min. The results are shown in Fig. 6. It can be seen that all of the dyeings carried out at 95°C are 1-6 MacAdams units lighter than the standard reference. While most of those carried out at 100°C closely approximate the results obtained under the dyeing conditions used for the standard.

The dyeings made under atmospheric conditions, 95° and 100°C, were found to be approximately four MacAdams units lighter (ΔL) than those made under pressure (120°, 125°, 135°C). This means that dyeings made under atmospheric conditions will require approximately ten (10) percent more dye than those under pressure to arrive at equivalent shades.

D. Air Force Blue 1549 Shade

Dyeings have been made on Dacron 54 and Dacron 64 using a pressure dyeing procedure at 125°C and dyeing formulations recommended by General Aniline and Film, Sandoz, and duPont. The color differences between these dyeings and the Air Force Standard are shown in Fig. 7 as total lightness difference (ΔL) and total color difference (ΔE) with both ΔE and ΔL being expressed in MacAdams units. With the exception of a duPont formulation on Dacron 54, all dyeings were darker (ΔL) than the Air Force Standard. The chromaticity differences (ΔC), not shown in Fig. 7, contribute negligibly to the overall color differences (ΔE). These results show that dyeing formulations can be readily adjusted to duplicate the Air Force Standard.

E. Dyeing Conditions and Abrasion

Single filaments of Dacron 54 and Dacron 64 which had been dyed at

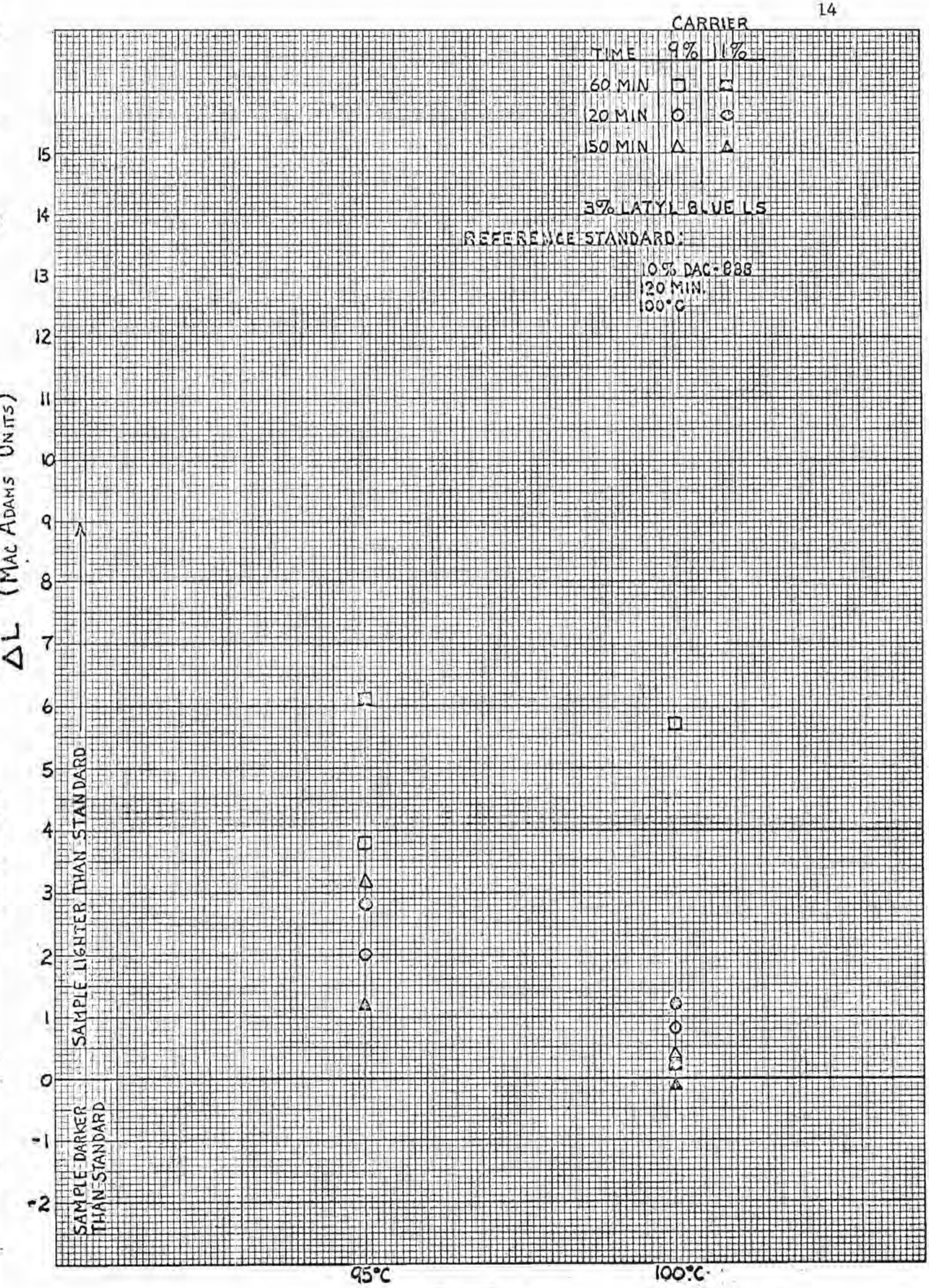
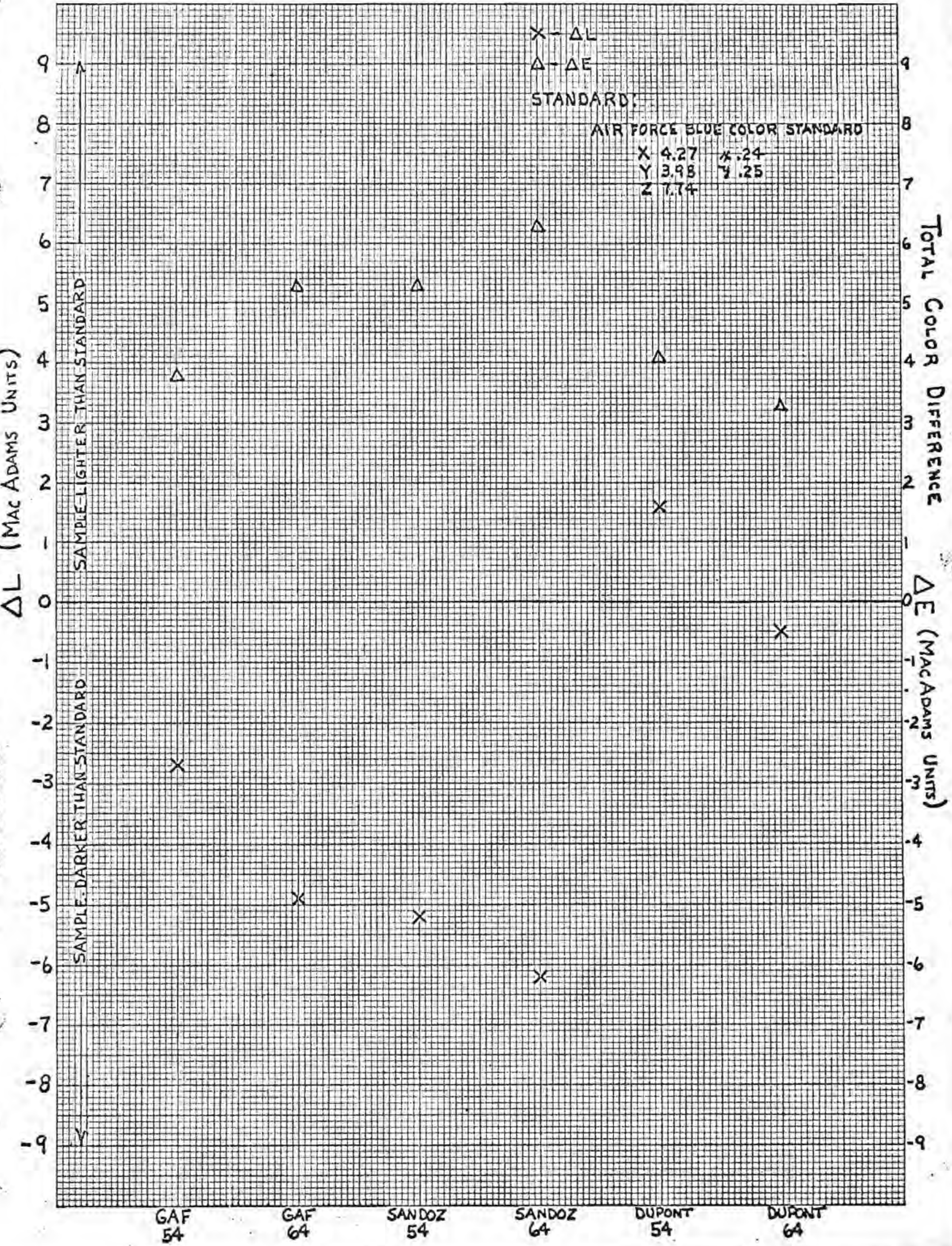

CARRIER
TIME 9% 11%
60 MIN
120 MIN
150 MIN
3% LATYL BLUE LS
REFERENCE STANDARD:
10% DAC-888
120 MIN.
100°C
ΔL (MAC ADAMS UNITS)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
SAMPLE LIGHTER THAN STANDARD
SAMPLE DARKER THAN STANDARD
95°C
100°C

FIGURE 6

FIGURE 7


X - ΔL
Δ - ΔE
STANDARD:
AIR FORCE BLUE COLOR STANDARD
X 4.27 x .24
Y 3.98 y .25
Z 7.74
ΔL (MAC ADAMS UNITS)
SAMPLE LIGHTER THAN STANDARD
SAMPLE DARKER THAN STANDARD
TOTAL COLOR DIFFERENCE
ΔE (MACADAMS UNITS)
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
GAF 54
GAF 64
SANDOZ 54
SANDOZ 64
DUPONT 54
DUPONT 64

$125^{\circ}C$ and $135^{\circ}C$ in the presence of 3.0% carrier (DAC-888) were abraded and compared with undyed, similarly abraded filaments (200 mg., N.F. for 1,2,5 hrs.). The dyed filaments have poorer abrasion resistance than the undyed filaments, Dacron 64 being in all cases poorer than Dacron 54. The increase in dyeing temperature from $125^{\circ}C$ to $135^{\circ}C$ results in a very noticeable decrease in abrasion resistance. Since good color yields can be obtained on both fibers at $125^{\circ}C$, dyeing at $135^{\circ}C$ is not recommended because of the deterioration in abrasion properties noted.

IV. Evaluation of Dyes

Dyes recommended by several dye manufacturers for the Air Force Blue shade are being evaluated. Twenty (20) disperse dyes have beeen applied to polyester fibers at two depths of shade. Spectrophotometric data necessary for determining dyeing formulations have been obtained for these dyeings. Light fastness tests have been made and it is concluded that it will be possible to meet the required light fastness standard of 80 S.F.H. (standard fading hours).

The evaluation of wool dyes is in progress.

E - 27-613

Bimonthly Technical Report Number 5

(15 May 1973 to 15 July 1973)

Exploratory Development on Polyester/Wool Uniform Fabric with Improved Durability and Appearance

Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

(Prepared under Contract No. F33615-72-C-1822 by
Georgia Institute of Technology, Atlanta, Georgia,
A. J. Maguire and W. C. Carter, authors)

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I. Status of Experimental Program to Delineate Effects of Variables in the Composition and Structure of Polyester/ Wool Uniform Fabrics on Abrasion Resistance

A. Timing

The schedule describing the expected progress in this experimental program has been described in the Interim Technical Report Number 2 for the period 15 November 1972 to 15 May 1973. It is estimated that the program is 3-4 weeks behind schedule due primarily to the shutdown of Florence Dye Works and Westbrook Spinning for the first two weeks in July. As of 31 July 1973, the dyeing and preparation of all blended tops have been completed and are in the hands of Westbrook Spinning. Westbrook has shipped one (1) yarn lot to Textile Research Services and weaving of the first fabric has begun. Westbrook has informed us that seven (7) of the remaining yarns are being processed now (31 July 1973) and starting 7 August the remaining eleven yarns will be shipped to Textile Research Services as they are completed at approximately two-day intervals.

B. Trip to Florence Dye Works and Westbrook Spinning

To insure that each step in this program was properly carried out, Mr. Maguire visited Florence Dye Works and Westbrook Spinning. Three days were spent at Florence Dye Works. Mr. J. P. Guerin and Mr. Maurice Guerin co-owners of Florence Dye Works have taken a personal interest in this project and have personally supervised the processing of fibers through dyeing, blending, and combing. While Mr. Maguire was present, at least one lot of each fiber type was dyed. Each lot of fiber was divided into at least two lots so that adjustments to dyeing formulas could be made if the first dyeing was found to be off-shade. The purpose of these dyeings was not that of exactly matching the Air Force Blue 1549 shade but rather to determine the physical property effects and workability of the dyeing procedure decided upon based on laboratory dyeings carried out at Georgia Tech. It was found that the dyeing procedures recommended to them were realistic and that formulations arrived at by joint efforts of Georgia Tech, dyestuff manufacturers, and Florence could be brought on shade with minor adjustments in dyeing formulations and dyeing procedures. Therefore, if the fabrics produced in this program meet government specifications with respect to tensile properties, fastness, and shade, the dyeing procedures used in this program can be used to produce the larger yardage required later in this program.

Mr. Maguire also discussed fabric finishing procedures to be used by Florence and was assured that Florence has the capability and interest necessary for handling small yardage lots in a manner typically required in production runs.

Mr. Maguire then visited Westbrook Spinning. Mr. Richard Spencer, President, and Mr. Donald Spencer, Plant Manager, offered many helpful suggestions based on their considerable experience in producing blended yarns having specifications almost identical with those required in this program. Mr. Maguire was assured that they would personally supervise the spinning of the experimental yarns.

II. Evaluation of the Fabrics Generated in the Experimental Fabric Program

The success of this project will depend on a comprehensive evaluation of the development fabrics and the materials generated in each step in their preparation since these fabrics represent those variations in fabric composition and structure which are believed to control abrasion resistance within the limitations specified in the statement of work. The description of the details of this evaluation have been prepared and will be supplied for inspection and criticism by Air Force Materials Laboratory personnel if requested.

III. Production of Specification Fabrics

Based on a detailed evaluation of the experimental fabrics currently being generated, specification fabrics will be prepared which meet the goals set forth in the statement of work for this project. In view of the extreme difficulties encountered in obtaining the services required for the preparation of the experimental fabrics, it was imperative that the services needed for the preparation of specification fabrics be obtained as soon as possible. Four types of services will be required, namely,

1) Top dyeing and blending
2) Spinning of yarn
3) Weaving
4) Fabric finishing.

There are assurances from Florence Dye Works and Westbrook Spinning that they will handle items 1 and 2. For the weaving of the fabrics, a new source was required. Quotations for this work have been requested from three firms:

The Bay Mill, Inc.
West Warwick, Rhode Island

Methuen International Mills, Inc.
Methuen, Massachusetts

Belltex Mills, Inc.
Philadelphia, Pennsylvania

Methuen has already replied affirmatively and Belltex has expressed a genuine interest in doing the work. Methuen can also finish the woven fabrics.

IV. Overall Status of Program

At the time of the initiation of this program, the target date for the production and evaluation of the developmental fabrics was about the seventeenth (17th) month. It is now estimated that this part of the program is approximately one month behind schedule. All of the other parts of the program are believed to be on schedule.

E-27-613

Bimonthly Technical Report Number 6

(15 July 1973 to 15 September 1973)

Exploratory Development on Polyester/Wool Uniform Fabric with Improved Durability and Appearance

Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

(Prepared under Contract No. F33615-72-C-1822
by Georgia Institute of Technology, Atlanta, Georgia,
W. C. Carter, author)

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I. Status of Experimental Program to Delineate Effects of Variables in the Composition and Structure of Polyester/Wool Uniform Fabrics on Abrasion Resistance

A. Timing

The status of the work to produce the twelve experimental fabrics required in this program is in accord with the schedule as described in the Bimonthly Technical Report Number 5 for the period 15 May 1973 to 15 July 1973. Westbrook Spinning has completed the spinning of the required yarns and all of the yarns are in the hands of Textile Research Services for weaving. The weaving of the twelve yarn lots is scheduled to be completed 5 October 1973. It is estimated that an additional two weeks will be required to complete the finishing of the fabrics at Florence Dye Works (target date 19 Oct. 1973). Sample quantities of the dyed wool and polyester top, the dyed and blended polyester/wool tops, and yarns prepared from the blended tops have been received at Georgia Tech and their evaluation is in progress as described below. The evaluation of finished fabrics will commence 22 October 1973.

B. Trip to Textile Research Services

To insure that each step in this program is properly carried out, Mr. Maguire has visited Textile Research Services. Mr. Clarence Davis of Textile Research Services stated that they were encountering no difficulties in winding, warping, and drawing in of the yarns and weaving of the fabrics.

C. Evaluation of Dyed and Blended Polyester/Wool Tops and Yarns Generated in Program

1. Composition of Yarns

Duplicate analyses of the twelve yarns for extractables and fiber content have been made. The methods used are in accord with those specified in the Federal Test Methods.

The results of these analyses are shown in Table I along with target analyses specified in the program.

TABLE I

FIBER CONTENT OF POLYESTER/WOOL YARNS

Yarn Designation	Polyester Component	Wool Component	Target Composition Polyester/Wool	Composition Found Polyester/Wool*
Y1	Dacron 64 3.0 den	64's	60/40	60.8/39.2
Y2	Dacron 54 3.0 den	64's	40/60	41.5/58.5
Y3	Dacron 64 3.0 den	64-70's	40/60	40.2/59.8
Y4	Dacron 54 3.0 den	64-70's	60/40	61.3/38.7
Y5	Dacron 64 3.0 den	64's	40/60	40.6/59.4
Y6	Dacron 54 3.0 den	64's	60/40	62.4/37.6
Y7	Dacron 64 3.0 den	64-70's	60/40	60.4/39.6
Y8	Dacron 54 3.0 den	64-70's	40/60	40.5/59.5
Y9	Dacron 54 3.0 den	64's	60/40	62.0/38.0
Y10	Dacron 54 3.0 den	64's	60/40	61.8/38.2
Y11	Dacron 54 4.5 den	64's	60/40	62.4/37.6
Y12	Dacron 35 3.0 den	64's	60/40	59.7/40.3

*These analyses are based on the oven-dry weight of the chloroform extracted yarns.

It is concluded that the blending of the dyed tops was accomplished as required in the program.

D. Yarn Count and Twist

Yarns prepared by Westbrook Spinning have been analyzed for size (count) and twist levels. The count for the Air Force Tropical worsted fabrics is 40's two-ply (worsted system) corresponding to an equivalent singles worsted count of approximately 20's. The yarn twist is 12 turns per inch in the singles and 12 turns per inch in the ply to produce a balanced twist.

These specifications were arrived at previously from an analysis of the standard Air Force uniform fabric. Federal Test Methods corresponding to ASTM Test Methods were used to obtain the following count and twist data:

TABLE II

WORSTED COUNT AND TWIST OF POLYESTER/WOOL YARNS

Yarn Designation	Worsted Count* (Equivalent Singles)	Yarn Twist (tpi) Target (Singles and Ply)	Found Singles	Ply
Y1	18.9	12	11.4	13.0
Y2	19.7	12	11.0	13.2
Y3	19.6	15	13.8	15.8
Y4	19.5	15	13.8	15.4
Y5	15.7**	15	13.7	16.0
Y6	19.8	15	14.1	15.9
Y7	19.3	12	11.5	12.8
Y8	20.6	12	11.2	13.4
Y9	18.7	12	11.5	13.2
Y10	20.1	18	16.7	19.9
Y11	20.1	15	13.8	15.6
Y12	20.1	15	13.9	15.7

*target 20's worsted system

**Y5 - this low value is due to a mistake made by Westbrook, 32's singles were made whereas their instructions were to prepare 40's singles. Thus, the fabric made from the yarn will be approximately twenty percent heavier than specified and its abrasion properties will be a function of the larger yarn size; however, in the statistical analysis of the abrasion properties of the fabrics, the effect of having the wrong yarn size (Y5) will be one of decreasing the variance due to main effects and increasing the variance attributed to error.

E. Color of Dyed Fibers and Blended Tops

Visual inspection of the individual dyed polyester and wool tops as well as of the blended tops indicates a close approximation to the Air Force target shade. There is no perceptible color difference between the ten (10) blended tops. Spectrophotometric analyses of these samples is underway.

F. Effect of Dyeing on Single Filament Tensile and Abrasion Properties

In view of the effect of dyeing on abrasion and stress-strain tensile properties previously reported, similar tests are being made on fibers taken from the dyed and blended tops. It is anticipated that the abrasion properties of the fabrics produced in this program will, in part, be related to these measured single filament properties. This work will include:

1. stress-strain curves

   a. breaking strength
   b. breaking elongation
   c. energy to break
   d. initial modulus

and

2. single filament abrasion

II. Dyeing Procedures Used at Florence Dye Works

The following dyeing procedures were used to produce the required Air Force 1549 Shade.

64's and 64-70's Wool

1.00% Avalon I.S. (o.w.f.)
5.00% Ammonium Sulfate (o.w.f)
0.95% Levalan Navy Blue IRL (o.w.f.)
0.38% Levanol Brilliant Blue FFG (o.w.f.)
0.075% Isolan Orange R (o.w.f.)
0.072% Isolan Yellow N.W. (o.w.f.)

All Polyester Fibers

1.00% Lyogen P (o.w.f.)
1.00% Lyogen DFT (o.w.f.)
12.00% Dilatin TC (o.w.f.)
3.00% Faron Blue ER (o.w.f.)
0.46% Faron Yellow E-RGFL (o.w.f.)
1.25% Faron Brilliant Red E-2BL (o.w.f.)
Dyed 2 hours at 212°F

After scoured with

2.00% sodium hydrosulfite (o.w.f.)
2.00% caustic soda (o.w.f.)
1.00% Ekaline G-80 (o.w.f.)
20 minutes at 160°F

Although these dyeings were accomplished with no difficulty by Florence Dye Works, it was found that, in the blending operations involving gilling and combing, considerable difficulty was encountered with 3.0 denier polyester fibers. However, with the 4.5 denier polyester fiber the blending operation was trouble free. It should be noted here that the standard Air Force material contains 3.0 denier polyester and 64's wool. Thus the polyester fibers are smaller than the wool fibers. The 4.5 denier polyester fiber, on the other hand, is approximately the same size as the wool fiber in 64's wool. It is interesting to note that Mr. Spencer of Westbrook Spinning also prefers to spin 4.5 denier polyester with 64's wool. In the analysis of the fabrics being prepared it will be possible to establish whether there is an advantage with respect to abrasion resistance in using 4.5 denier polyester with 64's wool rather than 3.0 denier polyester.

E-27-613

Bimonthly Status Report No. 7

(15 November, 1973 to 15 January, 1974)

Exploratory Development of Polyester/Wool Uniform Fabric With Improved Durability and Appearance

Air Force Materials Laboratory
Air Force Systems Command
Wright Patterson Air Force Base, Ohio 45433

(Prepared under Contract No. F-33614-72C-1822 by Georgia Institute of Technology, Atlanta, Georgia, W. C. Carter, Author)

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I Status of Experiment Fabric Program

In the Interim Report No. 3 for the period 14 May, 1973 to 15 November, 1973, the experimental work which had been done to evaluate samples of dyed top, blended dyed top, yarns, and loom fabrics generated in our experimental fabric program was reported. At the time this report was written, the experimental fabrics had not been finished by Florence Finishing Company. The finished fabrics have now been received and their evaluation is underway. Of primary importance in this program was the abrasion resistance of the fabrics, pilling and frosting. All twelve (12) finished fabrics in the experimental fabric program have been abraded using the wire-screen flat-abrasion method. The number of cycles of abrasion was in 1000 cycle increments to 12,000. After 12,000 cycles all of the fabrics exhibited appreciable color change due to frosting and, for this severity of treatment it was impossible to assess the effect of variables on abrasion resistance; however, when abraded for 5000 cycles, the samples differed significantly in appearance. In evaluating the abraded samples, the change in appearance was assessed visually with the illumination normal to the fabric surface and the angle of observation 45 degrees with respect to the fabric surface. Any evidence of pilling was noted. In addition, the samples were examined microscopically at low power in order to get a better assessment of the nature of the abraded surface. All of the experimental fabrics are typically slightly more hairy than the Air Force standard tropical fabrics.

Finishing processes not usually required for worsted fabrics are shearing and singeing. According to Military Specification MIL-C-21115G for tropical worsted uniform fabric, the finishing procedures specified included scouring, light fulling, brushing, shearing, pressing, and decating. In the finishing of our experimental fabrics, these finishing procedures were followed although it was not apparent from examination of the fabrics that the shearing had been sufficient to reduce the hairiness to an extend equal to that of the AF standard. It is assumed that the finishing processes employed in producing the AF standard were the same as those for our fabrics; however, there is evidence from miscropic examination of the standard that the fabric had been singed, thus reducing the hairiness. It should be noted that singeing is not included in the Military Specification MIL-C-21115G.

In order to show the effect of singeing on abrasion, we will return 25 yard samples of each lot to Florence Finishing for singeing. In order to compare the abraded fabrics (5000 cycles of abrasion), the grey scale ratings for the degree of color change were determined and are shown in Table I.

The following conclusions can be drawn from these data:

Variable 1. Type of Polyester

The two types of polyester used in the experimental design were Dacron 54 and Dacron 64, the latter being a less tough fiber than Dacron 54 and a fiber recommended for use in fabrics where pilling is a problem. Pilling is not the major problem in worsted fabrics, but rather frosting. It is clear that those experimental fabrics containing Dacron 64 are showing a greater change in appearance than those containing Dacron 54. Miscroscopically, fibrillation is more apparent with Dacron 64 than Dacron 54. Dacron 35 is inferior to Dacron 54 and no better than Dacron 64.

Variable 2 -Grade of Wool (Domestic)

The grade of wool was included in the experimental design in order to learn whether the quality of wool and the matching of fineness of the two fibers was important in abrasion. When the polyester fiber was 3.0 denier, the use of 64-70's wool results in a small improvement in abrasion compared with 64's wool. It should be noted

Table I

		40/60 Polyester/Wool			60/40 Polyester/Wool				
				Rating*			Rating*			Rating*
3.0 den Dacron 64	64's wool	F5	15	2.75	F1	12	3.25			
	64-70's wool	F3	15	3.25	F7	12	2.75			
3.0 den Dacron 54	64's wool	F2	12	3.50	F6	15	3.75	F9	12	4.00
								F10	18	4.50
	64-70's wool	F8	12	4.00	F4	15	4.50			
4.5 den Dacron 54/64's wool					F11	15	4.50			
3.0 den Dacron 35/64's wool					F12	15	3.00			
Air Force Tropical Std.					Std.	11	4.50			
Air Force Gabardine Std.							2.75			
Air Force Serge Std.							4.0			

*Fabric No. Yarn twist(t.p.i.) grey scale rating that sample F 11 represents a fabric in which the fineness of the two fibers are closely matched resulting in an improvement in abrasion resistance.

Variable 3 : Carbonizing

Carbonizing, a process used to remove cellulosic impurities from wool, not usually required for clean, well combed tops can result in damage to both wool and polyester fibers. In our experimental fabrics, it is not apparent that carbonizing contributes to abrasion resistance of polyester/wool fabrics. However, if this treatment is too severe, i.e. too high a concentration of sulfuric acid and conditions of temperature and time of treatment excessive, considerable damage to both fibers will result in poor abrasion resistance. In addition, if the acid is not neutralized and removed immediately following carbonizing, damage to both fibers will occur.

Variable 4 Composition of Blend (Polyester/Wool)

The Air Force Standard approximates a 60/40 polyester/wool composition. One-half of the experimental fabrics had this composition and one-half a composition 40/60 polyester/wool. The abrasion results indicate a small preference for the composition 60/40 polyester/wool.

Variable 5. Yarn Twist (t.p.i.)

In comparing most of the fabrics, the effect of yarn twist on abrasion is so small that it is masked by other effects. However, one group of fabrics differing only in yarn twist demonstrate a small improvement in abrasion resistance as the yarn twist is increased from 12 to 18 t.p.i.

Variable 6 - Denier of Polyester Fiber

A direct comparison was made of the effect of the denier of the polyester fiber by making two 60/40 polyester/wool fabrics equivalent in every respect except for fiber denier, 3.0 denier and 4.5 denier. The 4.5 denier polyester fiber closely matches the average filament size of 64's wool used in making the two fabrics.

The fabric containing the 4.5 denier fiber was very superior in abrasion to that containing the 3.0 denier fiber. This fabric was at least equal in abrasion to the standard Air Force tropical worsted standard. Sample F 6 containing the 3.0 denier Dacron 54 has a grey scale rating of 3.75 whereas Sample F 11 containing 4.5 denier Dacron 54 has a grey scale rating of 4.50.

At the time this project was started, gabardine and serge Air Force standards were supplied along with the tropical standard. Flat abrasion of these fabrics shows that the gabardine exhibits a much worse change in appearance that the tropical standard whereas the serge standard was about equal to the tropical standard.

It was determined that the tropical standard contains a polyester fiber chemically similar to Dacron 54 but definitely not like Dacron 64. This probably accounts for its good abrasion properties. This fact suggests the questions:

> Is the standard fabric supplied typical of the fabrics being used for uniforms with respect to the type polyester fiber?
>
> Are the fabrics being used equal in abrasion resistance?

II Tests to be Employed in the Evaluation of the Experimental Fabrics

A. Composition and Construction of Fabrics

		Federal Standards No.	ASTM or AATCC Method
1.	Fiber Content	2102	
2.	Polyester identification*		
3.	Yarns/inch	5050	ASTM D-1910
4.	Polyester denier*		
5.	Yarn count	4052	ASTD- 1423
6.	Yarn twist (singles and ply)	4054(singles) 4052(ply)	ASTMD-1422 ASTMD-1423

B. Fabric Properties

1.	Fabric construction	5041	ASTM-D-1910
2.	Fabric thickness	5030	ASTM D-1777
3.	Air-Flow Permeability	5450.1	ASTM·D 737
4.	Bending length	5202	ASTM D 1388
5.	Drape	5206.1	
6.	Monsanto Wrinkle Recovery	5212	ASTM D-1295
7.	Moisture regain	600	ASTM D- 629
8.	Abrasion of Textile fabric		ASTM D-1175
9.	Stoll flex abrasion	5300	
10.	Color change due to Flat abrasion (Frosting)		AATCC 119-1970
11.	Impeller Tumble Test		AATCC 93-1967 ASTM D-1175
12.	Breaking strength (Grab method)	5100	ASTM D-1682
13.	Tension Test - Breaking strength - Ravel	5104	ASTM D-1682

C. Color and Color Fastness

1.	Color*		
2.	Color fastness to wet dry-cleaning	5622	AATCC 85
3.	Color fastness to crocking	5651	AATCC 8
4.	Color fastness to light	5660	AATCC 16
5.	Color fastness to perspiration	5680	AATCC 15

*1. polyester identification - extraction and staining technique developed at Georgia Tech
2. polyester denier - Vibrascope measurements
3. color measurement - Diano instrument (latest modification of Color-Eye)

III Preparation of 500 Yard Pieces of Tropical Worsted Fabrics

As a result of the work done on the experimental fabrics relative to abrasion, it is concluded that plans for the production of 500 yard pieces required by the work statement can be made before the evaluation of the fabrics is complete. It is understood that such plans must meet the approval of the Air Force Materials Laboratory personnel. It is proposed that the additional fabrics necessary to complete this program will include:

1. Polyester type - Dacron 54
2. Denier of polyester - 4.5 d.p.f.
3. Fiber content - 60/40 and 40/60 polyester/wool.
4. Grade of wool, 64's and 64-70's

In addition, sample fabrics of 100% 4.5 denier Dacron 54 and 100% 64's wool should be prepared as reference points for abrasion and other fabric properties.

File: E-27-613

Bimonthly Status Report No. 8

(15 January, 1974 to 15 March, 1974)

Exploratory Development of Polyester/Wool Uniform

Fabric With Improved Durability and Appearance

Air Force Materials Laboratory
Air Force Systems Command
Wright Patterson Air Force Base, Ohio, 45433

(Prepared under Contract No. F-33614-72C-1822 by Georgia Institute of Technology, Atlanta, Georgia, W. C. Carter, Author)

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I. Introduction

In the Bimonthly Progress Report No. 7 for the period, 15 November, 1973 to 15 January, 1974, it was noted that the experimental fabrics were typically more hairy than the Air Force tropical standard and it was suspected that this hairiness was responsible for their somewhat poorer abrasion properties compared with the Air Force standard. As a consequence of this finding, 25 yard pieces of the experimental fabrics were returned to Florence Finishing Company for singeing. For the unsinged fabrics, the results of abrasion studies using the wire screen flat abrasion method to discover the degree of frosting were as follows:

1. Fabrics containing Dacron 54 showed less frosting than those containing Dacron 34 and Dacron 64.
2. Fabrics containing 64s - 70s grade wool showed slightly less frosting than those containing 64s grade wool.
3. Fabrics which had been carbonized were not significantly different in abrasion from those which had not been carbonized.
4. With respect to fiber content, 60/40 polyester/wool fabrics were slightly better in abrasion than 40/60 polyester/wool fabrics.
5. Yarn twist did not have a significant effect on abrasion behavior (12 tpi to 18 tpi)
6. A fabric containing 4.5 d.p.f. Dacron 54 showed less frosting on abrasion than an equivalent fabric containing 3.0 d.p.f. Dacron 54.

In the abrasion studies it was discovered that the color change due to abrasio as assessed visually, is very dependent on the washing procedure following abrasion. The standard abrasion method calls for a rinse in luke-warm water but does not specify how much and what type of agitation is involved in rinsing. In the subsequent testing of abraded samples, the method of rinsing was therefore standardized.

The results of abrasion obtained on the singed experimental fabrics are given in this report. These results will constitute a major part of the presentation to be made at the Technical Conference to be held at Georgia Tech, 30 April, 1974.

II. Abrasion Results on Experimental Fabrics (singed)

All abrasion tests were made according to Flat Abrasion-Frosting A.A.T.C.C. Method 119-1970. This method employs a wire screen as the abradant with a head load of 2.5 lbs. The fabric samples were abraded at five levels of abrasion, 1200, 2400, 4800, 7200, and 9600 cycles. The abraded fabrics were evaluated by five observers, two women and three men, and the color change on abrasion was expressed in terms of the A.A.T.C.C. Geometric Grey Scale for color change. The results are shown in Tables I-V. A duplicate test at 4800 cycles was made and a comparison with a previous 4800 cycle test is shown in Table VI. From an inspection of abrasion data, the following conclusions can be made:

1. Fabrics containing Dacron 54 exhibit less frosting than fabrics containing Dacron 35 and Dacron 64, particularly at abrasion levels of 7200 and 9600 cycles.
2. The quality of wool (64s versus 64s-70s) is not an important factor in abrasion relative to the importance of the type polyester used.
3. The fabric containing 4.5 d.p.f. fiber is somewhat better in abrasion than the fabric containing 3.0 d.p.f. Dacron 54.
4. Yarn twist (12 to 18 tpi) is not an important factor in abrasion.
5. Fabrics having a composition, 60/40 polyester/wool are slightly better than fabrics having a composition 40/60 polyester/wool with respect to color change on abrasion.
6. The Air Force tropical standards do not have the same abrasion properties indicating the possibility that different types of polyester fibers were used commercially. This was confirmed by staining tests made on the standard fabrics.
7. A comparison of these data on the abraded singed fabrics with those for the unsinged fabrics shows clearly that singeing is necessary to reduce the color change due to abrasion regardless of which polyester

is used. Singeing is also necessary to avoid pilling even for fabrics containing a pill resistant fiber such as Dacron 64. This was shown clearly in random-tumble pilling tests made on the unsinged and singed fabrics.

The abrasion data shown in Tables I-VI represent mean values for the visual assessment of the color change due to abrasion. In order to determine the level of confidence that the differences between these mean values are real, all of the individual assessments of color change on abrasion will be used in a statistical treatment of the data. In addition, color measurements are being made on both the abraded and unabraded fabrics. The color change as measured spectrophotometrically will be compared with that assessed visually.

III. Status of Other Tests Performed on Experimental Fabrics.

A list of all of the tests which are to be used in the evaluation of the experimental fabrics was included in the Bimonthly Progress Report No. 7. With the exception of the Stoll flex abrasion text, the random tumble pilling test, all of the tests have been performed and tables containing the experimental data are in preparation for the April 30 meeting at Georgia Tech. In addition to these tests, selected fabrics have been dry cleaned 10, 20, and 30 times by two methods, namely, Stoddard and perchloroethylene, in order to assess the effect of dry cleaning on abrasion resistance. The abrasion tests are in progress. In view of the fact that most of the tests require at least five individuals in the sample chosen for testing, it will be possible to statistically analyze the data obtained to determine the level of significance of the differences between mean values.

A complete analysis of all fabric test data will be included in the Interim Report No. 4 for the period, 15 November, 1973 to 15 May, 1974. At that time it will be possible to make recommendations with respect to the production run fabrics as well as the choice of textile manufacturers who will prepare the fabrics.

TABLE I

Test Method: AATCC 119-1970

COLOR CHANGE DUE TO FLAT ABRASION (FROSTING)

1200 CYCLES

Polyester	Wool	40/60 Polyester/Wool Sample No.	40/60 Polyester/Wool Results RATING*	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results RATING*	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results RATING*
Dacron Type 64 3.0 d.p.f.	64s	5-15	4.9	1-12C	5.0		
	64s-70s	3-15C	5.0	7-12	5.0		
Dacron Type 54 3.0 d.p.f.	64s	2-12C	4.9	6-15	5.0	9-12 10-18	5.0 5.0
	64s-70s	8-12	5.0	4-15C	5.0		
Dacron Type 54, 4.5 d.p.f./64s wool				11-15	5.0		
Dacron Type 35, 3.0 d.p.f./64s wool				12-15	5.0		
Air Force Tropical Standard No. 1							
Air Force Tropical Standard No. 2					4.9		
Air Force Gabardine Standard							
Air Force Serge Standard					5.0		

* GEOMETRIC GREY SCALE

TABLE II

Test Method: AATCC 119-1970

COLOR CHANGE DUE TO FLAT ABRASION (FROSTING)

2400 cycles

Polyester	Wool	40/60 Polyester/Wool Sample No.	40/60 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Result
			RATING		RATING		RATING
Dacron Type 64 3.0 d.p.f.	64s	5-15	4.3	1-12C	4.8		
	64s-70s	3-15C	4.4	7-12	4.9		
Dacron Type 54 3.0 d.p.f.	64s	2-12C	4.7	6-15	4.9	9-12	5.0
	64s-70s	8-12	4.7	4-15C	5.0	10-18	5.0
Dacron Type 54, 4.5 d.p.f./64s wool				11-15	4.9		
Dacron Type 35, 3.0 d.p.f./64s wool				12-15	4.9		
Air Force Tropical Standard No. 1							
Air Force Tropical Standard No. 2					4.5		
Air Force Gabardine Standard							
Air Force Serge Standard					5.0		

GEOMETRIC GREY SCALE -

TABLE III

Test Method: AATCC 119-1970

COLOR CHANGE DUE TO FLAT ABRASION (FROSTING)

4800 CYCLES

Polyester	Wool	40/60 Polyester/Wool Sample No.	40/60 Polyester/Wool Results (RATING*)	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results (RATING*)	Sample No.	Results (RATING*)
Dacron Type 64 3.0 d.p.f.	64s	5-15	3.9	1-12C	4.1		
	64s-70s	3-15C	4.0	7-12	4.0		
Dacron Type 54 3.0 d.p.f.	64s	2-12C	4.5	6-15	4.5	9-12	4.4
						10-18	4.5
	64s-70s	8-12	4.5	4-15C	4.4		
Dacron Type 54, 4.5 d.p.f./64s wool				11-15	4.6		
Dacron Type 35, 3.0 d.p.f./64s wool				12-15	4.1		
Air Force Tropical Standard No. 1							
Air Force Tropical Standard No. 2					3.6		
Air Force Gabardine Standard							
Air Force Serge Standard					4.6		

* GEOMETRIC GREY SCALE

TABLE IV

Test Method: AATCC 119-1970

COLOR CHANGE DUE TO FLAT ABRASION (FROSTING)

7200 CYCLES

Polyester	Wool	40/60 Polyester/Wool Sample No.	40/60 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results	Sample No.	Result
			RATING*		RATING*		RATING*
Dacron Type 64 3.0 d.p.f.	64s	5-15	3.3	1-12C	3.5		
	64s-70s	3-15C	3.6	7-12	3.4		
Dacron Type 54 3.0 d.p.f.	64s	2-12C	4.1	6-15	4.0	9-12	4.3
						10-18	4.2
	64s-70s	8-12	4.4	4-15C	4.5		
Dacron Type 54, 4.5 d.p.f./64s wool				11-15	4.5		
Dacron Type 35, 3.0 d.p.f./64s wool				12-15	3.8		
Air Force Tropical Standard No. 1							
Air Force Tropical Standard No. 2					3.3		
Air Force Gabardine Standard							
Air Force Serge Standard					4.2		

* GEOMETRIC GREY SCALE

TABLE V

Test Method: AATCC 119-1970
COLOR CHANGE DUE TO FLAT ABRASION (FROSTING)
9600 CYCLES

Polyester	Wool	40/60 Polyester/Wool Sample No.	40/60 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results
			RATING*		RATING*		RATING*
Dacron Type 64 3.0 d.p.f.	64s	5-15	3.0	1-12C	3.1		
	64s-70s	3-15C	3.4	7-12	3.2		
Dacron Type 54 3.0 d.p.f.	64s	2-12C	3.5	6-15	4.0	9-12	3.3
						10-18	3.1
	64s-70s	8-12	3.8	4-15C	4.3		
Dacron Type 54, 4.5 d.p.f./64s wool				11-15	4.1		
Dacron Type 35, 3.0 d.p.f./64s wool				12-15	3.1		
Air Force Tropical Standard No. 1							
Air Force Tropical Standard No. 2					2.9		
Air Force Gabardine Standard							
Air Force Serge Standard					3.0		

* GEOMETRIC GREY SCALE

TABLE VI

Test Method: AATCC 119-1970

COLOR CHANGE DUE TO FLAT ABRASION (FROSTING)

4800 CYCLES (DUPLICATE RUN)

Polyester	Wool	40/60 Polyester/Wool Sample No.	Results RATING*		60/40 Polyester/Wool Sample No.	Results RATING*		Sample No.	Result RATING	
Dacron Type 64 3.0 d.p.f.	64s	5-15	4.2	3.9	1-12C	4.1	4.1			
	64s-70s	3-15C	4.4	4.0	7-12	4.0	4.0			
Dacron Type 54 3.0 d.p.f.	64s	2-12C	4.5	4.5	6-15	4.6	4.5	9-12	4.5	4.[illegible]
								10-18	4.4	4.[illegible]
	64s-70s	8-12	4.5	4.5	4-15C	4.8	4.4			
Dacron Type 54, 4.5 d.p.f./64s wool					11-15	4.7	4.6			
Dacron Type 35, 3.0 d.p.f./64s wool					12-15	4.1	4.1			
Air Force Tropical Standard No. 1						4.5				
Air Force Tropical Standard No. 2						4.1	3.6			
Air Force Gabardine Standard										
Air Force Serge Standard						4.4	4.6			

* GEOMETRIC GREY SCALE

File: E-27-613

Bimonthly Status Report No. 9

(15 May to 15 July, 1974)

Exploratory Development on Polyester/Wool Uniform Fabric With Improved Durability and Appearance

Air Force Materials Laboratory
Air Force Systems Command
Wright Patterson Air Force Base, Ohio 45433

(Prepared under Contract No. F-33614-72C-1822 by Georgia Institute of Technology, Atlanta, Georgia, W. C. Carter, Author)

I. Introduction

The Interim Technical Report Number 4 for the period 15 November, 1973 to 15 May, 1974 describes in detail the results of the experimental fabric program to discover those variables in the composition, construction, and processing of polyester/wool uniform fabrics which affect their durability, particularly "frosting" due to abrasion. Based on the results obtained, recommendations have been made with respect to the preparation of production-run fabrics. A request for authorization to prepare the production-run fabrics has been made and approved. This report describes the status of the production-run fabrics.

II. Status of Production-Run Fabrics

A description of the fabrics recommended and approved for the final phase of this program is given in the Interim Technical Report Number 4 for period 15 November, 1973 to 15 May, 1974.

The sources of materials and services for the production-run fabrics are as follows:

1. Materials

Wool 64s top	-	Burlington Industries, Inc.
Dacron 64 (3.0 d.p.f.) top	-	Burlington Industries, Inc.
Dacron 54 (3.0 d.p.f.) top	-	Burlington Industries, Inc.
Dacron 54 (4.5 d.p.f.) top (this top was left over from the experimental fabric program)	-	Georgia Tech

2. Services

a. Dyeing of tops and blending of top

Florence Dye Works
Woonsocket, Rhode Island

b. Yarn Spinning

Westbrook Spinning Company
Westbrook, Maine

c. Weaving and finishing of fabrics

Methuen International Mills
Methuen, Massachusetts

The wool and polyester tops have been shipped to Florence Dye Works and were received approximately July 1. Due to the fact that Florence Dye Works, like many textile mills, ceases production the first two weeks of July, the dyeing of the tops was not started until about July 17. It has been estimated by the firms who are providing services in the production of the fabrics that the maximum time required will be 18 weeks (approximately 6 weeks each for Florence Dye Works, Westbrook Spinning Co., and Methuen International Mills.

E-27-613

Bimonthly Status Report No. 10

(15 July to 15 September, 1974)

Exploratory Development on Polyester Wool Uniform Fabric with Improved Durability and Appearance

Air Force Materials Laboratory
Air Force Systems Command
Wright Patterson Air Force Base, Ohio 45433

(Prepared Under Contract No. F-33614-22C-1822 by
Georgia Institute of Technology, Atlanta, Georgia
W. C. Carter, Author)

I. Introduction

The Interim Technical Report Number 4 for the period 15 November, 1973 to 15 May, 1974 contains a description of those fabrics recommended for preparation as the production-run fabrics which will be made into uniforms for a service test program to be conducted by the Clothing Branch, Aeronautical Systems Division. Following the receipt of an authorization to prepare the production-run fabrics, their production was begun. The sources of materials (wool and polyester top) and services (dyeing, blending, yarn manufacture, weaving, and fabric finishing) were described previously in the Bimonthly Status Report No. 9 for the period 15 May to 15 July, 1974. This brief report describes the status of these fabrics.

II. Status of Production-Run Fabrics

The dyeing and blending of the individual wool and polyester tops, started as of the middle of July were completed about 15 September. It had been estimated that six (6) weeks would be required for this part of the work; however, approximately nine (9) weeks were required. This means that the original estimate of eighteen weeks for the production of the fabrics must be revised to twenty-one weeks. Thus, the estimated completion date is 10 December. The blended tops have been received from Florence Dye Works and laboratory evaluations to establish color, color uniformity, and composition of blends are underway.

Mr. Guerin of Florence Dye Works reports that the blending of the dyed tops went smoothly. He points out again, as in the case of the fiber blending for the experimental fabrics, that 4.5 denier polyester fiber processes much better in the blending operation than the 3.0 denier polyester fiber.

The blended tops are now being spun into yarn at Westbrook Spinning Company. We have been assured by Mr. Spencer at Westbrook and Mr. Hildebrand at Methuen International Mills that they will make every attempt to meet the time schedule of six (6) weeks each for their parts in the production of the fabrics.

III. Final Technical Report

During the time required for the making of the production-run fabrics, efforts at Georgia Tech have been spent in compiling all information necessary for the writing of the Final Technical Report.

E-27-613

Interim Technical Report No. 1
(15 May to 15 November 1972)

Exploratory Development of Polyester/Wool

Uniform Fabric with Improved Durability and Appearance

Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

(Prepared under Contract No. F 33615-72-C-1822
by Georgia Institute of Technology, Atlanta,
Georgia, W. C. Carter, author)

Abstract

The objective of this program is to explore means for producing polyester/wool uniform fabrics which have improved durability and appearance, drape, and tailorability. Fabrics having improved durability and appearance must be more resistant to wear, and the change in appearance after being worn, commonly referred to as frosting, must be minimized.

A worn Air Force uniform has been studied to gain an understanding of the frosting problem. From the study and a laboratory study of the flat-abrasion of a standard Air Force fabric, it is concluded that there is differential wear of the two fibers, the wool component being more easily damaged and removed. The damage to wool does not lead to a frosted appearance. The abrasion of the polyester results in fibrillation, and the frosted appearance of the fabric is due to the high amount of light scattered by the small polyester fibrils produced on abrasion.

Additional work has been done to determine the nature of frosting. When polyester/wool fabrics are abraded prior to dyeing, it is apparent from the difference in the shade of the unabraded and abraded areas, after dyeing the single fiber component of the blend fabric, that wool is preferentially worn away before appreciable damage to the polyester component occurs.

It has been established that careful selection of dyeing procedures and control of the dyeing process must be exercized to minimize damage to both the polyester and wool fibers.

Polyester fibers representing variations in chemical composition, physical structure, and stress-strain behavior have been chosen for investigation of their abrasion resistance with the view that it will be possible, as a result of this work, to specify those structural parameters

which are important in abrasion. Four commercial polyester fibers have been processed to yarn and fabric. Evaluation of the abrasion resistance of these fabrics is underway.

Dyes having the required spectral and fastness properties necessary to produce the Air Force Blue shade have been chosen and the spectrophotometric data necessary for matching the specified shade have been obtained from laboratory dyeings.

Two textile manufacturing firms were contacted with the intention of contracting with them to supply important textile processing details necessary for the success of the project. Both companies responded negatively.

Table of Contents

I. Introduction

Fabrics for military uniforms as specified by the Department of Defense are described as tropical, serge, and gabardine constructions produced from intimate blends of polyester and wool fibers. The fabric and fiber specifications are clearly set-forth in Military Specifications MIL-C-21115G, MIL-C-83048, and MIL-C-19176 G.[1] All of these military fabrics as well as non-military fabrics and garments of similar fiber composition and structure possess the property of an undesirable change in appearance described as a lightening or whitening effect caused by mild abrasive action such as that involved in the normal wearing of a garment. This has been referred to as frosting and has been defined as "a change of fabric color caused by localized abrasive wear. It may be the result of differential wear, as in multi-component blends in which the fibers do not match in shade, or of the abrasion of single fiber constructions in which there is a variation in or incomplete penetration of dyestuff. Frosting is sometimes referred to as 'differential wear' or 'fibrillation.'"[2] Another characteristic of fabrics containing polyester fibers is "pilling", a physical process which occurs in the surface of a fabric taking the form of small balls made up of fibers. Pilling is the usual complaint with fabrics produced from low density, low twist, yarns in a low density fabric construction whereas, military uniform fabrics show little "pilling" due to the use of high density, high twist yarns; they are, however, subject to frosting.

The purpose of this program is to develop polyester/wool Air Force Uniform fabrics having improved drape, handle, fabricability, wear, and resistance to frosting over current Air-Force fabrics. At the time this program was started, there was no satisfactory explanation for frosting.

Frosting has been used to describe the appearance of abraded polyester/ cotton, polyester/rayon and polyester/wool fabrics. Several possible causes for the objectionable changes in fabric appearance due to abrasion have been suggested but there has been little assessment of their relative importance in the problem. It is not surprising that there are conflicting views since there are many uncontrolled variables both in the fiber content of the military uniform fabrics and in the chemical, thermal, and mechanical treatments involved in their manufacture. Military Specifications for uniform fabrics include specifications for both wool and polyester fibers to be used. For wool, 64's grade U.S. Standard (or finer) is specified. For the polyester fiber component, the only requirement is that it be made from poly (ethyleneterephthalate), either homopolymer or modified polymer, 3 denier, semi-dull. It is well known that polyester fibers derived from either the homopolymer or modified polymers can be produced which have a broad spectrum of physical properties and thus, would be expected to possess widely different abrasion and pilling resistance. Variations in the thermal, chemical, and mechanical treatments required to produce fabrics meeting military specifications would be expected to cause appreciable differences.

The usual explanation for frosting of polyester/wool uniform fabrics is differential wear of the two fibers, wool being preferentially worn away. Frosting is also attributed to fibrillation of wool, poor dye penetration of both fibers, and the difference in color between the two fibers. Polyester fiber manufacturers are hesitant to admit the possibility that the polyester component is responsible for the change in appearance due to wear. The fiber manufacturers discuss quite freely the pilling tendency of commercially available polyester fibers and the effects of fabric construction on pilling tendency; however, there is little published information with respect to their abrasion resistance, particularly when the fibers are present in fabric constructions which have little tendency to pill such as that characteristic of military uniform fabrics. From this discussion, it is not surprising that a comprehensive understanding of the mechanism of frosting is needed. It is necessary to establish whether the change in appearance called frosting is due to a change in appearance of the wool component or of the polyester component. A comprehensive understanding of the mechanism of frosting should lead to possible means for improving the abrasion resistance of the uniform fabric through choice of polyester, best dyeing and finishing processes, and yarn and fabric construction.

II. Frosting of Polyester/Wool Air Force Blue 1549 Fabric: Its Cause

A. Study of Worn Air Force Uniform

A worn Air Force uniform has been studied to gain an understanding of the "frosting" problem. The entire uniform was not available and only a sleeve of the uniform was supplied by the Air Force Materials Laboratory. The uniform had been worn 110 times and dry-cleaned 44 times. Badly frosted and unfrosted areas of the fabric were examined optically at low power (-40x) and at higher magnifications (up to 500x) using the scanning electron microscope. In order to establish which of the two fibers were responsible for the frosted appearance, the wool component was removed by treating the fabrics with a 5.0% solution of sodium hypochlorite. This removal of wool was found to be quantitative with no apparent damage to the polyester fiber and with no effect on the dye in the fiber. The fabrics resulting from this treatment were similarly examined by optical microscopy and scanning electron microscopy.

At low magnification, it is apparent that many fibers have been abraded away leaving fiber ends which have a crystalline appearance, free of dye. At higher magnification (SEM), the broken ends of the damaged polyester fibers are shown to be highly fibrillated whereas those of wool are blunt in appearance with little fibrillation. The cuticle is missing from some damaged wool fibers. A comparison of the frosted and unfrosted fabrics, before and after the removal of wool, leads to the following conclusions:

1. There is a differential wear of the two fibers, wool being more easily damaged.
2. The polyester component is damaged, leading to fiber ends which are highly fibrillated.

3. The frosted appearance of the worn area is unchanged by the removal of wool, showing conclusively that the polyester fiber is responsible for the frosted appearance.
4. Since both the polyester and wool fibers were found microscopically to be well penetrated by dye and dyed to an approximately solid (i.e., equivalent) shade, the frosted appearance is attributed to high light scattering by the polyester fibrils leading to an increase in the luminosity of the fabric.

B. Study of the Flat-Abrasion of Air Force Blue 1549 Fabric

A study has been made of the resistance to flat-abrasion of the Air Force Blue 1549 fabric to determine whether the frosting produced has the same character as that produced in the worn uniform fabric. In addition, it was desirable to know the severity of testing that should be used in studying the effect of various modified fabric constructions, fiber processing procedures, and wet processing procedures on the abrasion resistance of the uniform fabric in order to produce an improved product.

The flat-abrasion test used is that described in the Technical Manual of the American Association of Textile Chemists and Colorists, Test Method 119-1970.[2] This test calls for the Stoll Universal Wear Tester Model CS-22C with a frosting attachment. The abrading surface in the method is a standard stainless steel wire screen. A single test by this method consists of 1200 abrasion cycles. The Blue 1549 fabric was subjected to 14,400 cycles of abrasion in 1200 cycle increments. Each abraded sample was examined microscopically (-40x) and the change in color estimated by comparison with a standard geometric grey scale as specified in the test and by quantitative color measurements using the I.D.I. Color Eye. The fabrics were then washed in Stoddard solvent and color measurements made. Following this, the wool component was removed with aqueous sodium hypochlorite. After conditioning, the color of the fabrics was again determined.

The measured color of each abraded sample was compared with that of a control unabraded sample. The color differences are expressed in terms of MacAdams color difference units: ΔE, total color difference, ΔL difference in lightness, and ΔC, chromaticity difference. The results are shown in Figures 1 through 4. The change in ΔE and ΔL with increasing abrasion is in good agreement with the changes noted visually and correlate well with the ratings for the degree of frosting expressed in terms of a standard geometric grey scale of color difference. Up to 3600 cycles, the frosting is negligible, corresponding to a 4 to 5 rating on the geometric grey scale. The small measured color changes is probably due to the initial chromaticity change resulting from the preferential damage and removal of surface wool fibers. Frosting is barely perceptible at 4800 cycles. At 7200 cycles, the polyester fibers become severely damaged but not broken away from the fabric. Further abrasion, up to 12,000 cycles, leads to a breaking away and removal of the damaged fibers with little change in frosting. At 13,200 cycles there is again a larger increase in frosting. It would appear from Figure 1 that the frosting occurs in stages. This is less apparent after washing with Stoddard solvent. A comparison of Figure 2 and 3 clearly shows that the polyester fiber is primarily responsible for the color change. Both the trends and magnitudes of ΔE and ΔL values are the same for the blend fabric and the fabric containing polyester fiber alone.

The results of this work indicated that in order to improve the durability of the uniform fabric, the most durable polyester fiber must be used. In

7 X 10 INCHES
KEUFFEL & ESSER CO.
MADE IN U.S.A.

FIG 1 FLAT ABRASION OF AIR FORCE BLUE 1549 FABRIC

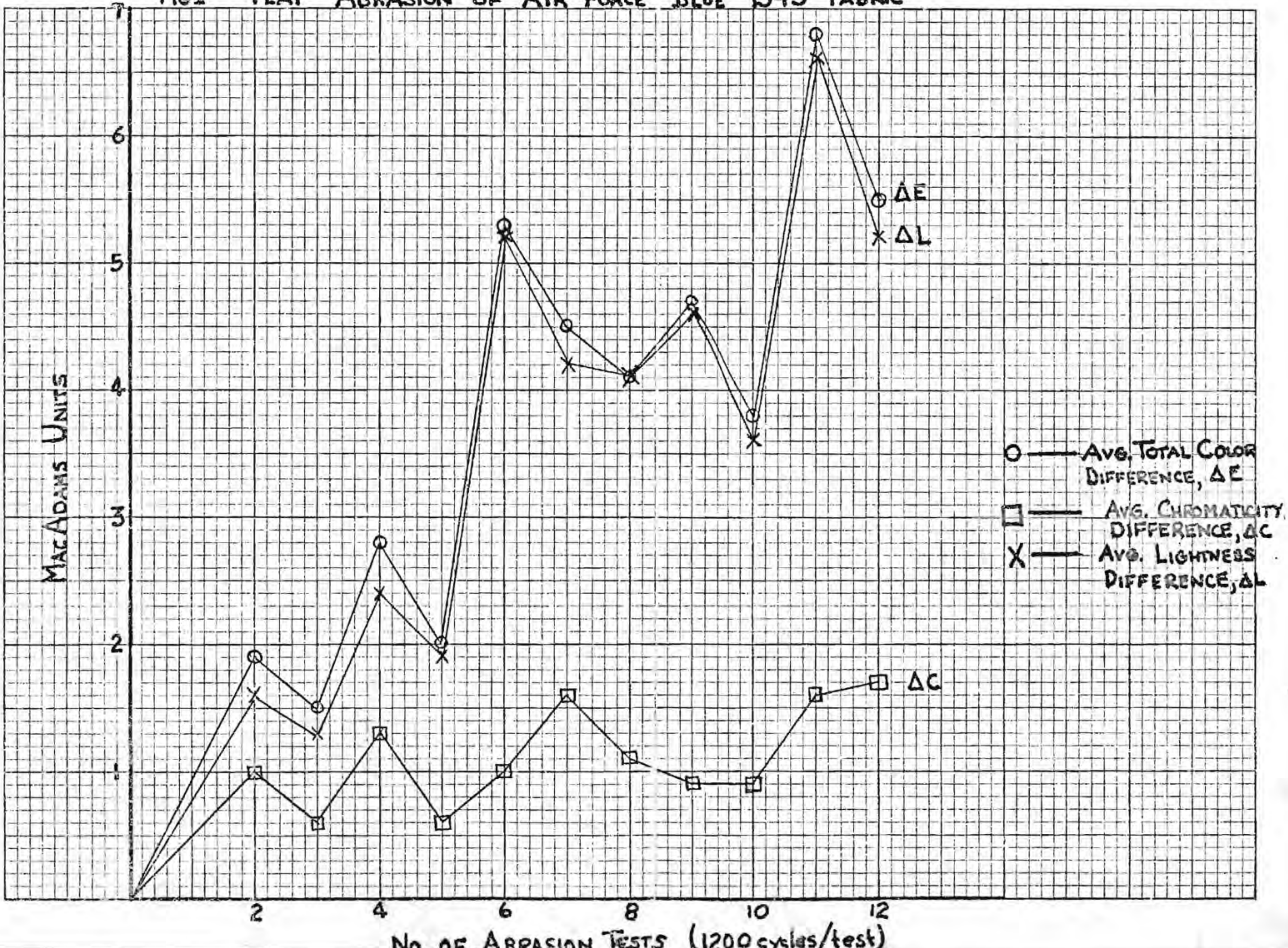


FIG 2 FLAT ABRASION OF AIR FORCE BLUE 1549 FABRIC

FABRIC WASHED IN STODDARD SOLVENT

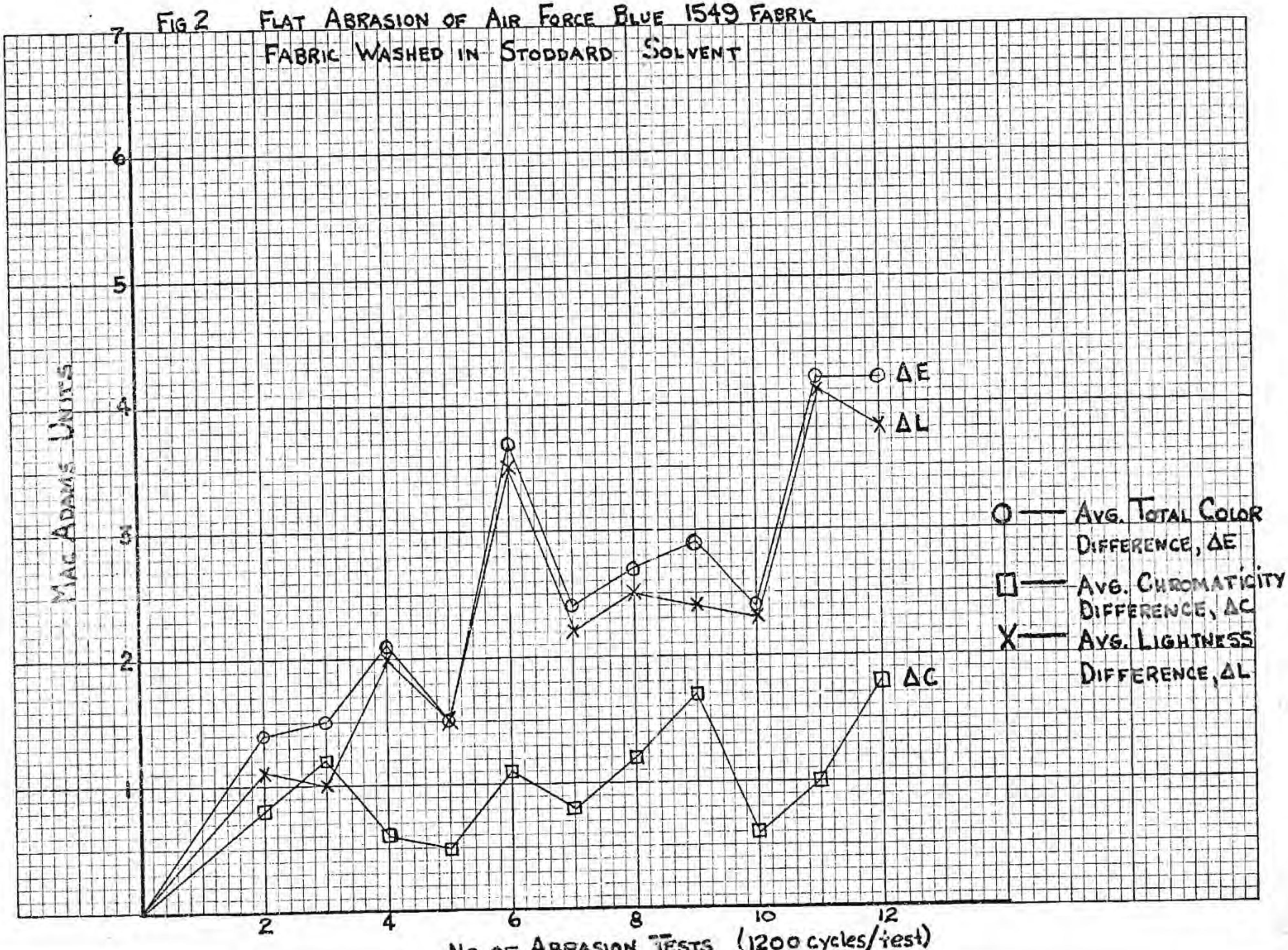
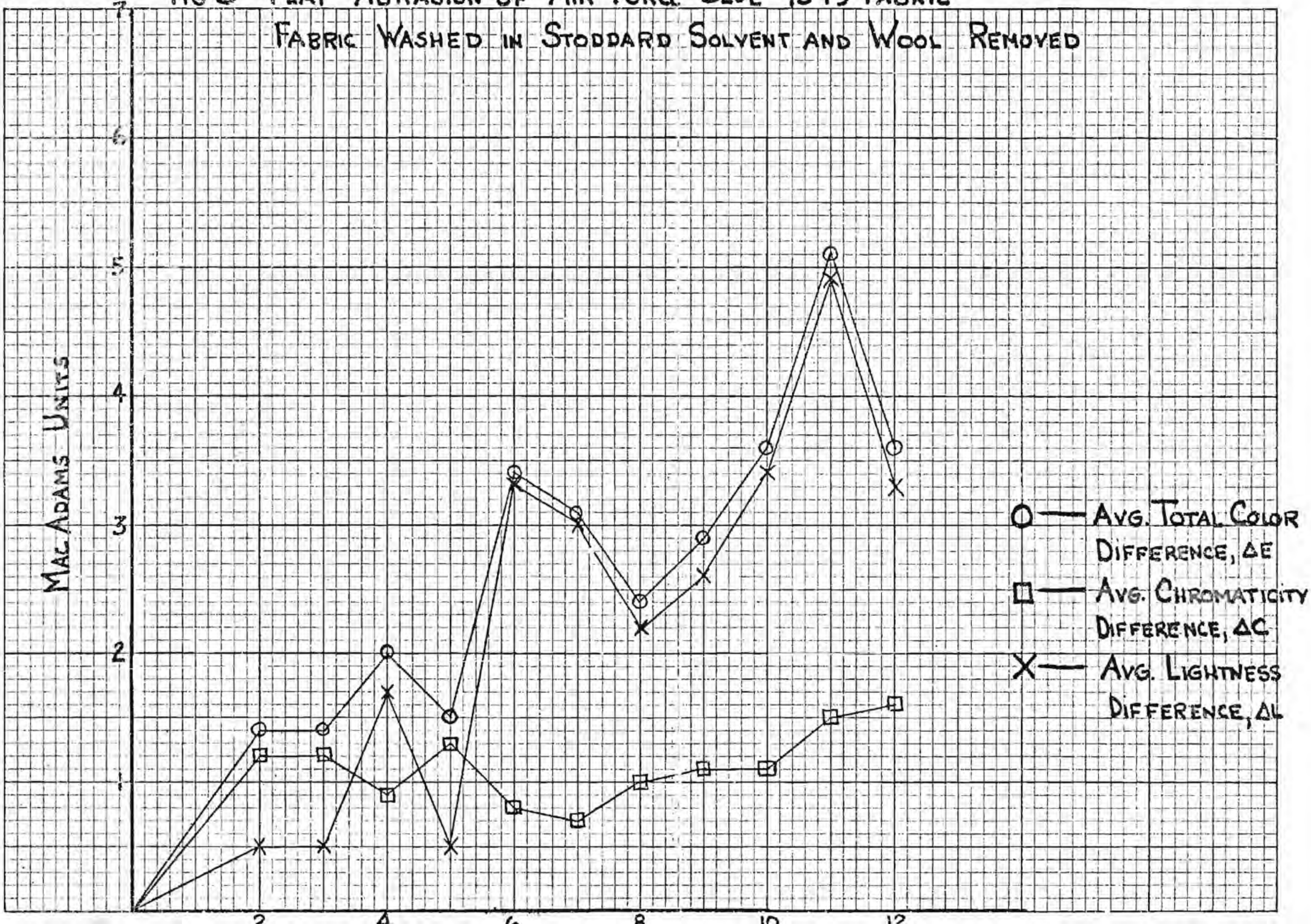


FIG 3 FLAT ABRASION OF AIR FORCE BLUE 1549 FABRIC

FABRIC WASHED IN STODDARD SOLVENT AND WOOL REMOVED



KEUFFEL & ESSER CO.

Fig 4 Average Color Difference Values (ΔE) For Abraded Sample, Washed Sample, and Wool Removed Sample

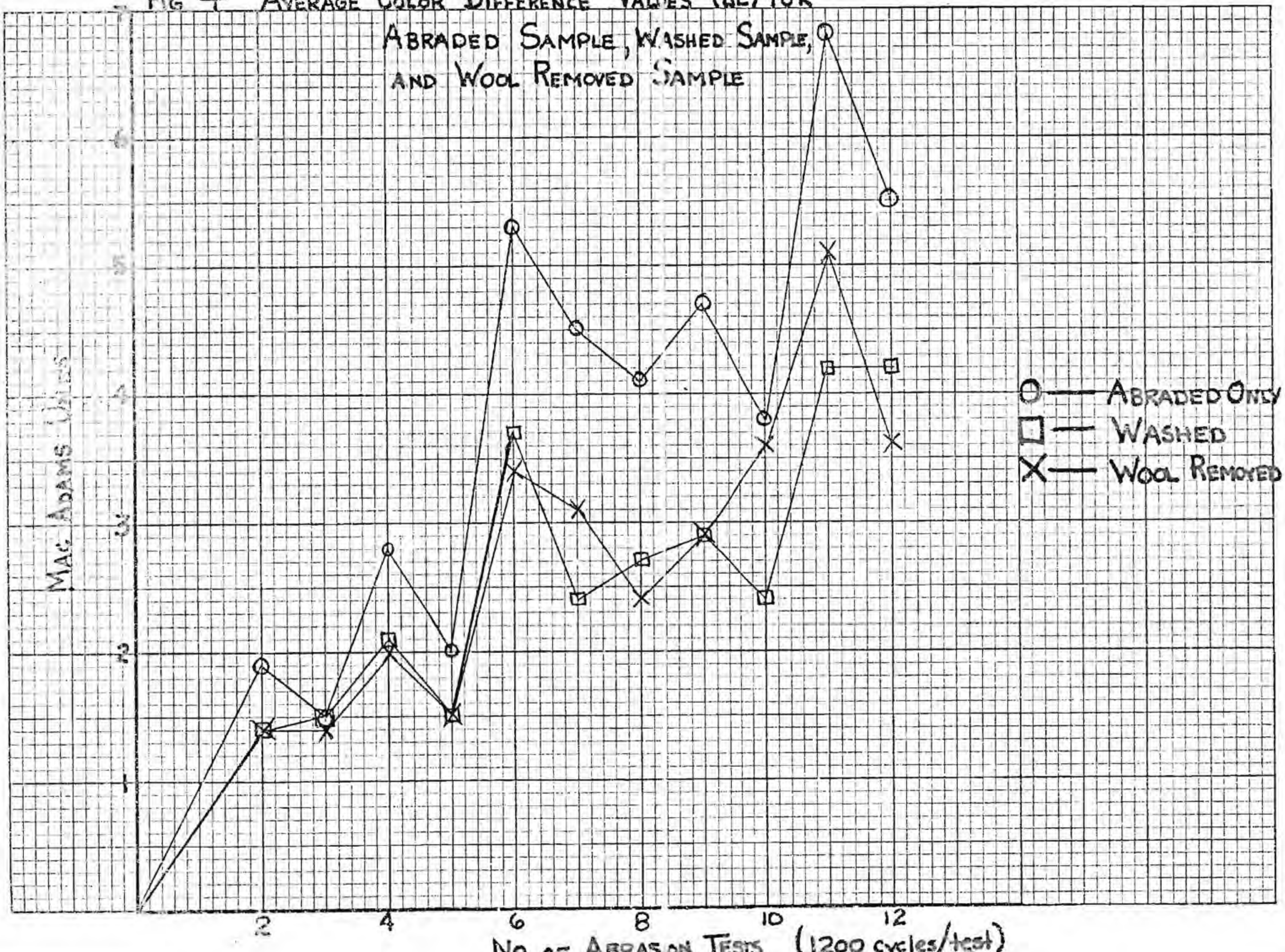
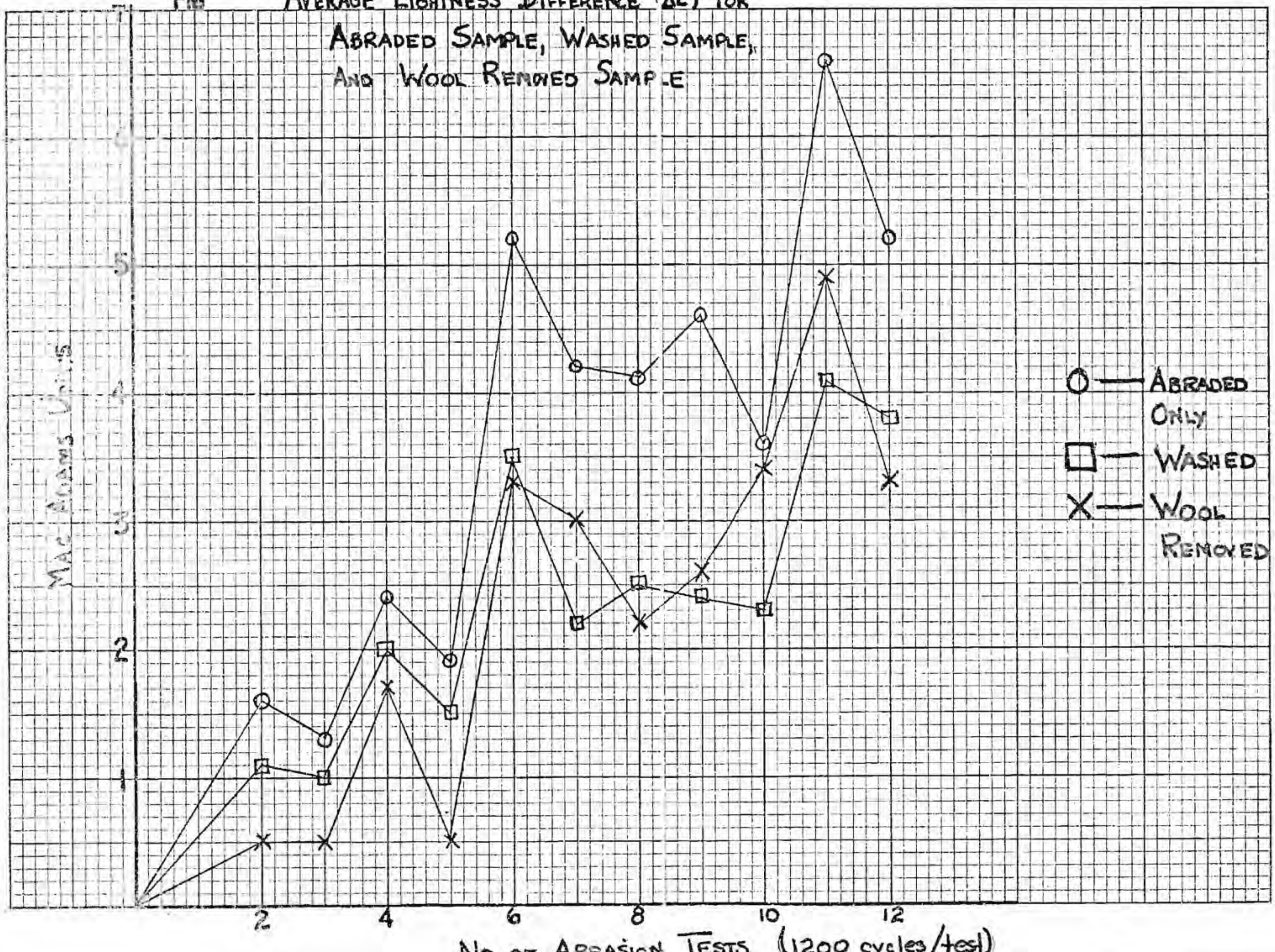


Fig. Average Lightness Difference (ΔL) for Abraded Sample, Washed Sample, and Wool Removed Sample



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addition, those dyeing and finishing conditions must be chosen which result in:

1. Solidity of shade (union-shade)
2. Good fiber penetration by dye
3. Minimum damage to both wool and polyester.

From examination of the worn Air Force uniform and flat abraded standard Air Force fabric, it was concluded that the wool is worn away preferentially and the frosted appearance is due primarily to the polyester component. In this work, the wet processing conditions used in making the fabrics were unknown. Therefore, to provide more positive evidence, an unscoured, undyed Dacron 54/wool fabric was abraded prior to dyeing. In this way, the effect of wet processing on abrasion was eliminated. The fabric was abraded for 3600 cycles using the Stoll Universal Wear Tester. One of the abraded fabrics was dyed, with a disperse dye, Latyl Blue LS. Under the dyeing conditions used, the polyester component was well-dyed and the wool component was only slightly stained. A second abraded fabric was dyed with a chrome dye, Acid Chrome Blue RRA. Only the wool component dyed. The abraded areas of the fabric dyed with the disperse dye was darker than that of unabraded area, whereas, the reverse was found for the fabric dyed with the chrome dye. These results are consistent with the previous conclusion that wool is preferentially worn away.

III. Selection of Polyester Fibers

As a result of the examination of the wear and flat abrasion of the Air Force Uniform Fabric, it was concluded that, in order to improve the durability of the fabric, the most durable polyester fiber must be used.

Polyester fibers are manufactured in the U.S.A. by at least ten (10) companies. Each company produces a range of chemical types as well as a range of physical types within each chemical type. The evaluation of all of these available types would be a formidable task. Therefore, if only a small number of fiber types are to be chosen for this work, some reasonable logic must be exercised in their choice. The logic being followed in this program is as follows:

The premise for the selection of the polyester fibers is that the polyester fiber which is best for application in uniform worsted fabrics is that fiber which has the best compromise of chemical and physical (mechanical) properties. The chemical property of prime importance is the susceptibility of the fiber to chemical damage in wet processing including dyeing, decatizing, carbonizing, etc. The physical properties include overall stress-strain behavior, abrasion resistance, crease resistance, etc.

The chemical and physical properties of commerical polyester fibers are a consequence of the chemical and physical structures which are built into the fiber in the making of the polymer and its conversion to fibers. Published information is meager concerning the chemical and physical [illegible] which are exhibited by commercial fibers. Most polyester fibers [illegible] the same chemical structure, namely, poly (ethyleneterephthalate); [illegible] commercial fibers exist in which this polymer is modified. For example, the so called basic dyeable fibers are really copolymers in which a small amount of a sulfonated comonomer replaces some of the terephthalic acid in the polymerization. Other chemical modifications are those which include polymeric blocks whose structure is different from that of the poly (ethyleneterephthalate) repeating unit and polymers in which terephthalic acid is replaced by another dicarboxylic acid and/or ethlene glycol is replaced by another diol.

With respect to physical variations, the commercial polyester fibers differ in their average molecular weight and probably in their molecular weight distribution. In addition, variations in fiber spinning, drawing, and thermal treatments lead to fibers having differences in degree of molecular order (crystallinity, crystallite size and perfection, molecular orientation, etc.).

Thus, in view of these chemical and physical variations in structure it would not be surprising to find significant variations in fiber properties.

Based on a limited knowledge of the properties and structural parameters of commercial polyester fibers, the following fibers were chosen for investigation:

Dacron type 54
Dacron type 64
Dacron type 35
Dacron type 59

Although these fibers are made by one manufacturer, namely E. I. duPont de Nemours and Company, they represent many of the variables in stress-strain behavior, abrasion resistance, crease recovery, etc. An extensive characterization of these fibers is being made for comparison [illegible] commercially available fibers. This characterization [illegible]

1. Stress-strain behavior (initial modulus, breaking extension and strength, energy to break)
2. Fiber to fiber and fiber to metal friction and abrasion
3. Crimp
4. Sonic modulus
5. Specific birefringence index
6. Density
7. Molecular weight (relative to each other)

Sufficient 1½ inch, 3 denier per filament, semi-dull staple has been obtained to prepare yarn and fabric for dyeing and flat abrasion studies. Once the fibers have been characterized and the fabric properties determined, it will be possible to specify those structural parameters which are important in abrasion. At this point the fiber which has optimum abrasion properties will be chosen, and other fiber manufacturers will be contacted to find out if they market fibers having similar properties. If necessary, the fibers they recommend will be similarly evaluated.

As a part of this study, it will be necessary to determine the effect of chemical processing on the abrasion properties of polyester and wool fibers. Some of this work has been done and the results of the work are reported in this report; however, fibers of comparable denier and fabrics of comparable construction were not available at this time.

A. Characterization of Selected Polyester Fibers

1. Stress-Strain Behavior

The stress-strain behavior of 3.0 denier semi-dull Dacron 35, [illegible], Dacron 59, and Dacron 64 fibers have been determined. The [illegible] were made on 1.0 inch guage length samples at an extension [illegible] per cent per minute. The resulting stress-strain curves are essentially the same as those given by duPont, Figure 5 and Table I.

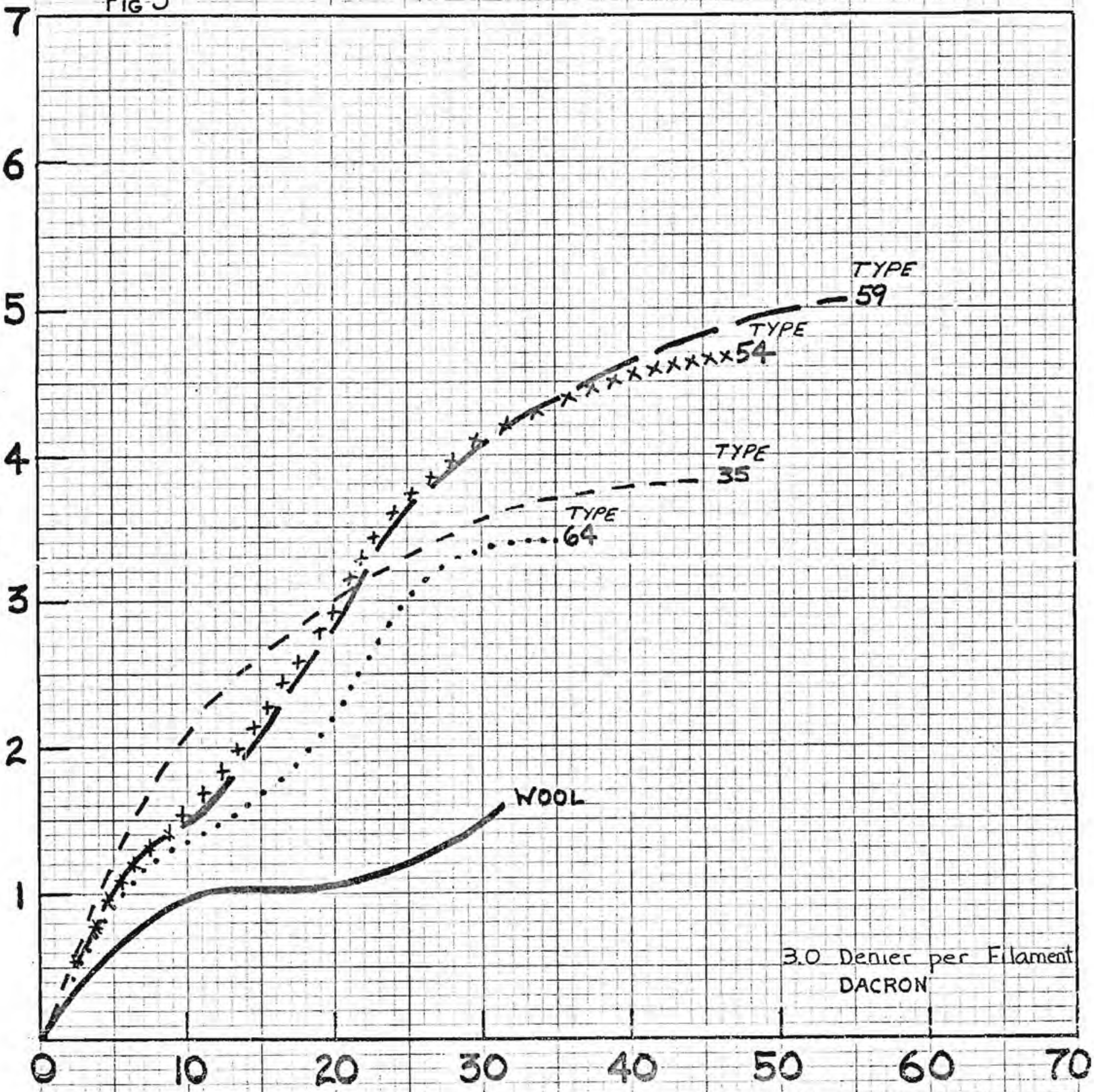
Table I

Analysis of Stress-Strain Curves
for Polyester Fibers

Dacron Type	Tenacity g-wt/den	Breaking Extension %	Specific Work to Rupture dyn-cm/den	Initial Modulus g-wt/den
35	3.5 (3.75)*	44 (43)	1064 (1987)	46.6
54	5.0 (4.7)	42 (45)	1571 (1362)	24.0
59	5.1 (5.0)	55 (53)	1674 (1744)	28.0
64	3.4 (3.4)	43 (34)	654 (648)	26.0

*(all figures in parenthesis have been calculated from curves published in du Pont Technical Bulletin D-243)

Fig 5



7
6
5
4
3
2
1
0
10
20
30
40
50
60
70
Tenacity, gm./den.
Elongation, %
Type 59
Type 54
Type 35
Type 64
Wool
3.0 Denier per Filament
DACRON

A guage length of 1.0 inch was required in these measurements because of the staple length available, 1.5 inches.

2. Single Filament Abrasion of Polyester Fibers

Single filaments of Dacron 54 and Dacron 64 (3 denier per filament) were abraded against a tungsten wire ($\sim$8 mil diameter) under a normal load of 3 grams for Dacron 64 and 4 grams for Dacron 54. After various times of abrasion, the friction of the abraded surface against a stainless steel wire (50 mg. normal load) was determined. Scanning electron micrographs were also made of the abraded fibers. The following conclusions are drawn from this work:

1. The abrasion resistance of Dacron 64 is poorer than that of Dacron 54. (Dacron 64 will not withstand abrasion when the load normal to the fiber is 4 grams.)

2. There is evidence of fibrillation damage of both fibers; however, the character of the fibrillation is different for the two fibers. Small fibrils are produced in both cases, whereas, long longitudinal cracks are noted primarily for Dacron 64 which become very evident when the fiber fails.

3. The friction of the fibers against stainless steel increases with the time of abrasion with little difference between the two fibers.

As a result of this work, it was concluded that the normal forces applied in single filament abrasion were too large. A fatigue apparatus capable of abrading single fibers under normal loads approaching those involved in standard flat-abrasion tests and speeds up to 1800 cycles per minute is now being used to assess the relative abrasion resistance of the selected polyester fibers. It has been established that a normal load of 200 mg. is sufficient to give appreciable abrasion in ten hours of abrasion (12,000 cycles). The choice of a normal load of [illegible] mg. is not completely arbitrary since it is based on a calculated estimate of the normal load which is used in the AATCC Flat Abrasion Test.[2] This work to establish the relative abrasion resistance of the four selected polyester fibers will be completed in December, 1972.

B. Conversion of Polyester Fibers to Fabrics

The polyester fibers which have been characterized are being converted to yarns whose construction is identical with that of the yarns used in the standard military fabric. The preparation of these yarns will be completed December 1. For flat abrasion evaluation before dyeing and changes in abrasion properties due to dyeing, knit fabrics are being made from the prepared yarns.

Then knit fabrics are being prepared in a tight enough construction for assessing the relative abrasion resistance of the four fibers. The time involved in making these fabrics is short compared with that required for producing woven fabrics making possible a quicker evaluation of the fibers. Woven fabrics will also be made to verify the results obtained using the knitted fabrics.

IV. Examination of Current Practice in the Manufacture of Polyester/Wool Air Force Blue 1549 Fabric

A. Fiber Producers

To establish current practice with respect to processing procedures for polyester/wool and current ideas with respect to the mechanism of frosting polyester fiberproducers, dye-stuff manufacturers, and textile firms who produce polyester/wool worsted uniform fabrics were contacted. As far as the mechanism of frosting is concerned little insight has been gained from the fiber producers. None of the fiber producers have made a positive recommendation with respect to the choice of polyester fiber with the possible exception of E. I. duPont de Nemours and Company. The personnel of duPont are very knowledgeable of the frosting problem. In their examination of the same worn Air Force uniform examined at Georgia Tech, they conclude that the change in the appearance of the uniform was due to the polyester component. Their experimental results are in complete agreement with those described in this report. They also conclude that the mechanism of frosting is independent of the polyester fiber used although the magnitude of frosting will depend on the type polyester used. Dacron 54 is recommended because of its superior durability and toughness compared with others that are used, namely Dacron 64, Dacron 59, and Dacron 35. Dacron 54 is a less-fibrillating fiber. In spite of these recommendations, they stated that a considerable amount of Dacron 64, a pill resistant fiber, is used for uniform fabrics rather than Dacron 54.

With respect to fiber and fabric processing procedures which could lead to improved properties, they recommend [illegible] carbonizing of the fabric should be avoided since it results in damage [illegible] fibers. They also recommend dyeing procedures which will result [illegible] minimum fiber damage and finishing processes which will provide good fiber mobility, e.g., milling and dolly washing.

In contrast with the recommendations of duPont, other fiber producers and dyers seem to be in general agreement that a pill resistant fiber such as Dacron 64 would be perferred to Dacron 54, a fiber which has lower pill resistance. It is concluded that this lack of agreement as to the best fiber is a consequence of a poor comprehension by most parties of the mechanism of pilling, mechanism of frosting, and the relation between pilling and frosting.

The polyester fiber producers contacted include:

1. American Enka Corporation
2. FMC Corporation
3. Celanese Corporation (Fiber Industries, Inc.)
4. Monsanto Company
5. Hystron Fibers, Inc.
6. Tennessee Eastman Co.
7. Hoechst Fibers, Inc.
8. E.I. du Pont de Nemours, Inc.

B. Dye Manufacturers

Eight (8) dyestuff manufacturers have been contacted and have responded. They have been most helpful, supplying recommended dyes for both fibers, dyeing procedures, dye formulation for both fibers and spectrophotometric curves for their recommended dyes. The classes of dyes recommended for the wool and polyester components are as follows:

1. For wool component

   a. Milling acid dyes
   b. Acid metalized dyes
   c. Mordant dyes
   d. Neutral dyeing metalized dyes
   e. Soluble leuco vat dyes

2. For polyester component

   a. [illegible] dyes

The dyeing recommendations clearly indicate that the preferred dyeing procedure is to dye each fiber component separately in top form instead of piece dyeing. Dye manufacturers as well as fiber producers generally recommend stock dyeing of wool and polyester for the production of the Air Force fabric rather than piece dyeing. Experience at Georgia Tech indicates the reasons for this preference:

1. Better control of color match with stock or top dyed fibers.
2. No staining of wool by disperse dyes in stock dyeing.
3. In stock or top dyeing the problem of poor dye penetration encountered in dyeing the high density worsted fabric is avoided.

Standard wool dyeing procedures are used for the wool component. The recommended procedures for polyester are either atmospheric dyeing (at 100°C) with the use of dyeing carriers or pressure dyeing (at $\sim$130°C) with a small amount of dye carrier. This has been verified in dyeings made at Georgia Tech.

In the piece dyeing of the polyester/wool blend in fabric form it has been demonstrated that prolonged dyeing times at 100°C and excess dye carrier lead to a decrease in the abrasion resistance of both polyester and wool. At a dyeing temperature of $\sim$130°C, the effect of extended dyeing times and carrier is even more pronounced, the wool component being severely damaged. As a result of this work, it is concluded that the two fibers should be dyed separately in top form, the wool being dyed using conventional dyeing procedures and the polyester fiber being dyed at 100°C in the presence of a carrier or at 120-130°C with no carrier or very small amounts of carrier. In dyeing polyester, the important considerations are the choice of dyeing conditions and times of dyeing as short as possible to minimize damage to the fiber.

Samples of all dyes recommended by dye manufacturers have been obtained. The recommended disperse dyes have been applied to Dacron 54 and Dacron 64 and the acid and chrome dyes to wool. Shade cards for each dye have been made and spectrophotometric curves established.

C. Textile Manufacturers

Two textile manufacturing firms were contacted with the intention of contracting with them to supply important textile processing details necessary for the success of the project. These firms were J. P. Stevens and Burlington Industries. A copy of the work statement sent to these manufacturers as well as a detailed outline of an agenda for meetings with their representatives are appended. Both companies responded negatively (see appended letters from J. P. Stevens and Burlington Industries).

V. Analysis of Standard Air Force Blue 1549 Fabric

A. Description of Standard Fabric

cloth, Tropical
Burlington
8305-926-6659
DSA-100-69-C-1477
Lot 8
Roll 6110

B. Fiber Content Analysis

Average polyester content 58%
Average wool content 42%

These values are based on the weight of the fabric conditioned at 70°F, 65% relative humidity.

C. Fabric Construction Analysis

Average warp ends/inch 54
Average filling yarn/inch 45
Average weight in oz/sq. yd. (conditioned weight) 5.79

D. Yarn construction analysis

1. Filling Yarn

(1) Ply Yarn
(a) Twist per inch 10.7
(b) Contraction 1.3%
(c) Yarn Number Worsted System 20's

(2) Single Yarn

(a) Twist per inch 10.9
(b) Yarn Number Worsted System 40.3

2. Warp Yarn

(1) Ply Yarn

(a) Twist per inch 10.9
(b) Contraction 1.1%
(c) Yarn No. Worsted System 20's

(2) Single Yarn

(a) Twist per inch 10.3
(b) Yarn Number Worsted System 38.9

3. Summary of Yarn Construction (ASTM D-1244)

(1) Warp Yarn 38.9:Z 10.3/2: S10.9 tpi
(2) Filling Yarn 20.3:Z 10.9/2: S10.7 tpi

Based on the above calculations it can be concluded that both warp and filling yarns are essentially identical in construction and are made by plying two ends of 40/s worsted count yarn.

E. Analysis of Standard Air Force Blue 1549 Shade

The tropical Air Force Standard fabric was analyzed spectrophotometrically using the I.D.L Color-Eye. Measurements were made using light source C and light source A. Color specification are given below in terms of the tristimulus values X, Y, Z and chromaticity coordinates, x and y:

	Light Source C	Light Source A
X	.0426	.0453
Y	.0405	.0405
Z	.0795	.0239
X	.2620	.4000
Y	.2491	.3700

A detailed analysis has been made of the report prepared by J.P. Stevens and Company, Inc., under Contract No. AF 33(657)-16558 entitled "Development of Shade Standard and Shade Tolerance in Blue 1549 Wool/Polyester Cloth, Stock Dyed Conforming to Type III of Specification MIL-C-21115B". This analysis consisted primarily of an examination of spectrophotometric data supplied in the report. The following conclusions are drawn:

1. Although shade tolerance levels were established by Stevens, they are not considered realistic, being so small (less than one (1) MacAdam color difference unit) that one could easily attribute the tolerance levels to random instrumental errors in the making of spectrophotometric measurements. In addition, there were inconsistencies in the data. For example, a full red is actually lighter than a thin red based on the data supplied.

2. The color standard supplied by the Air Force to J.P. Stevens, as well as the color standard established by

J.P. Stevens is radically different from the color standard supplied to Georgia Tech as part of this contract, being much lighter than the standard supplied to Georgia Tech. Evidently, more than one blue shade has been standard for uniforms. The color specifications for the J. P. Stevens standard and that supplied to J. P. Stevens by the Air Force are as following:

	Air Force	J. P. Stevens
X	.2281	.2382
Y	.2226	.2257
Z	.4091	.4286
X	.2653	.2669
Y	.2589	.2528

VI. Program Schedule

A program schedule for the polyester/wool program is appended. Phase I of this program includes the evaluation of Government provided Blue 1549 uniform fabric, determination of the cause of frosting, a review of polyester fibers suitable for this application, selection of polyester fibers, and investigation of possible solutions to the problem. This interim report clearly shows that the goals set forth in Phase I are being accomplished on schedule.

Phase II deals with the dyeing phase of the program. This part of the program is somewhat behind schedule because of the need for a high temperature dyeing apparatus not available at Georgia Tech. This need was not anticipated at the time the proposal for this program was prepared since it was generally considered that the dyeing of both fiber components could best be accomplished at a temperature of approximately $100^{\circ}C$. It now appears that pressure dyeing (120° - $130^{\circ}C$) is an important consideration in achieveing a more abrasion resistant polyester. Thus a high temperature dyeing apparatus was required. This problem has been solved by the purchase of the apparatus, delivery date, December, 1972.

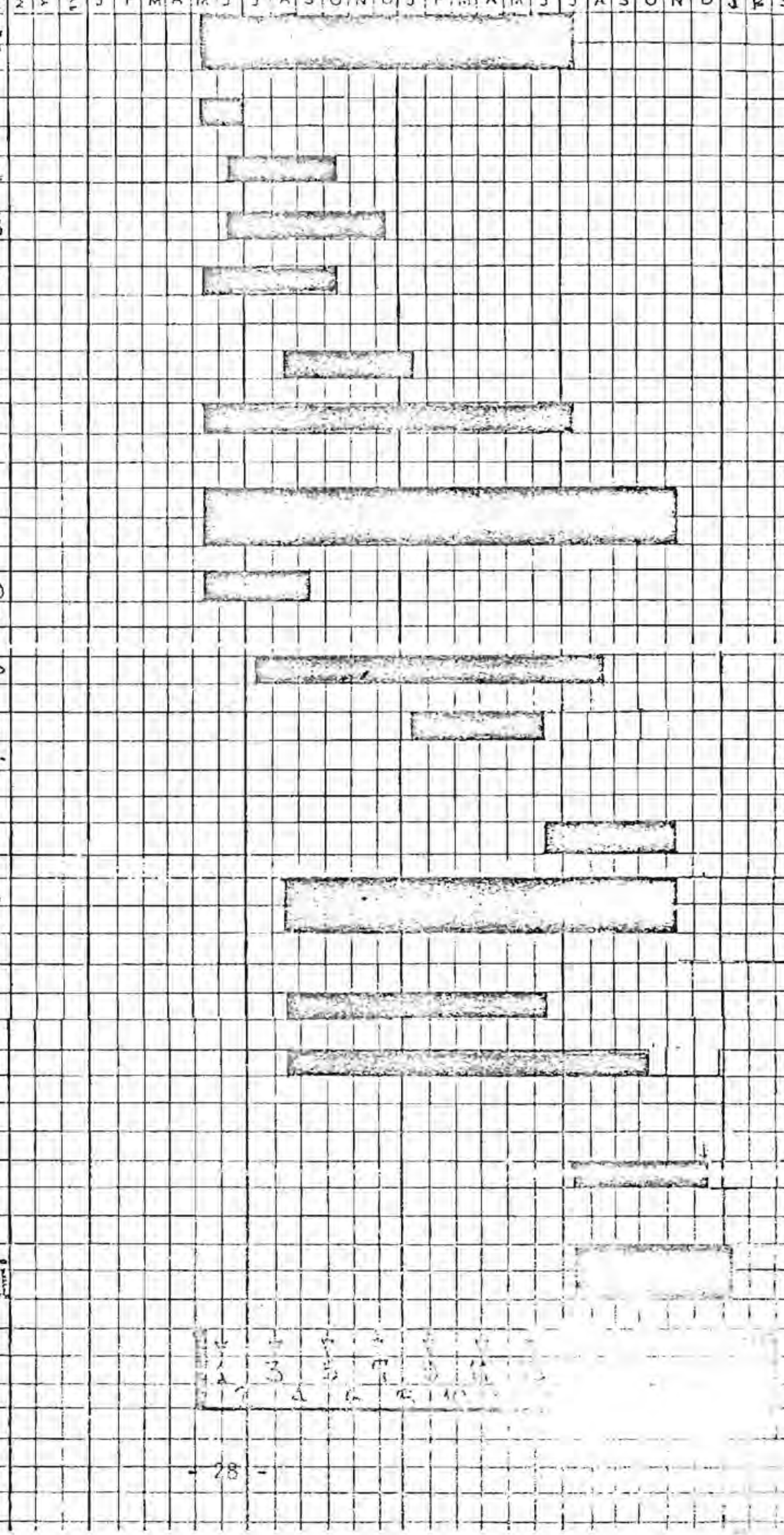
The most pressing problem in the program at this time is that of obtaining the consulting services of a major textile manufacturing firm. Both companies have responded negatively. Other processors and finishers of polyester/wool blend worsted fabrics are being sought.

POLYESTER/WOOL UNIFORM FABRICS WITH IMPROVED DURABILITY AND APPEARENCE

PROGRAM SCHEDULE

AS OF DATE 15 MAY 72

PRIOR SCHEDULE DATES — FY 1972 · FY 1973 · FY 1974 · 1974 — CY 1972 · CY 1973



PHASE I FROSTING D:F

1. EVAL. OF GOVT PROVIDED 1549
2. DETERMINE POLYESTERS USED.
3. REVIEW FIBERS SUITABLE FOR UNIFS
4. VERIFICATION & DETERMINATION OF FROSTING & SHININESS
5. SELECT 3 POLYESTERS
6. INVESTIGATION OF POSSIBLE SOLUTIONS TO PROBLEMS

PHASE II DYE & BLENDING.

1. REVIEW DYESTUFFS, TECH & PROCED FOR DYEING POLY STOCK & WOOL TOP
2. PREBLEND DYE TEST. OF POLY/WOOL TOP
3. DEVELOP. OF TOP & PIECE DYEING TECHNIQUES & FORMULATION OPTIMIZATION
4. SCALE-UP PROCESS

PHASE III-PREP, EVAL & TEST

1. BLEND INVESTIONS & RATIO DETERMINATION.
2. DESIGNING, WEAVING & EVALUATION OF SPECIFICATION & DEVELOPMENTAL FABRICS
3. FABRIC SELECTION (6) PRODUCTION & TESTING OF 500 YD LOTS.

SPEC. DATA & FINAL TECH REPT

ATTACH-I

VII. References

1. Military Specification MIL-C-21115 G
   Cloth, Tropical: Wool, Polyester/Wool
   23 October, 1970

   Military Specification MIL-C-83048 (USAF)
   Cloth, Serge Polyester/Wool
   6 September 1967 and Amendment 1,
   26 February 1969

   Military Specification MIL-C-10176 G
   Cloth, Gabardine: Wool,
   Polyester and Wool
   24 April 1970

2. AATCC Text Method 119-1970
   Technical Manual of the American Association of Textile Chemists and Colorists, 1970, p. 108

Work Statement to Textile Manufacturers

Program: "Exploratory Development of Polyester/Wool Uniform Fabrics with Improved Durability and Appearance"

The purpose of this program is to explore means for producing polyester/ wool Air Force uniform fabrics with improved durability and appearance, drape, and sewability. In the manufacture of these fabrics there are many processes involved which influence the properties of the finished fabrics. The manufacturers of synthetic fibers have agreed to provide information with respect to the use of their fibers in uniform fabrics. Those important textile processing details which affect the properties of the finished fabric must be supplied by worsted fabric manufacturers. The transfer of this information will be accomplished through meetings with appropriate, knowledgeable representatives of J. P. Stevens, Inc. These meetings will consist of two meetings to be held at Georgia Tech and several visits by Georgia Tech personnel to appropriate worsted fabric manufacturing plants. It is expected that representatives of the Air Force Materials Laboratory will participate in these discussions.

On a continuing basis, Georgia Tech will supply information on contract development, progress reports, and recapitulation of joint meetings to the textile manufacturer for their comment back to Georgia Tech and the Air Force Materials Laboratory. Additionally, recommended additions, deletions, and/or comments to the work plan will be provided.

Detailed Outline of Agenda for Meeting with
Representatives of Textile Manufacturers to Discuss Program:

"Exploratory Development on Polyester/Wool
Uniform Fabrics with Improved
Durability and Appearance"

The Purpose of this meeting is three-fold:

1. To describe in detail the program of work
2. To present progress of work to date
3. To discuss specific areas of work where input from textile manufacturers would be of benefit to the program

I. Program Objectives

The objective of this program is to explore means for producing polyester/wool uniform fabrics which have improved durability and appearance, drape, and tailorability. Fabrics having improved durability and appearance must be more resistant to wear, and the change in appearance after being worn, commonly referred to as frosting, must be minimized. Although the emphasis in this outline of work is the "frosting" of polyester/wool fabrics, it is also a requirement of this program to develop improved dyeing procedures and to produce fabrics having improved drape, sewability, and processibility.

II. Outline of Work

A. Mechanism of Frosting

The first phase of the project has as its objective to determine the cause of frosting, specifically to answer the following questions:

1. Which fiber, polyester or wool, is damaged on abrasion?

2. Is the change in fabric appearance, referred to as frosting due to--

   a. The light scattering (reflection, refraction, and absorption) characteristics of the damaged fiber (change in its surface, fibrillation, poor dye penetration in fiber, etc.)?

   b. The difference in the appearance of the two fiber components and its emphasis due to differential wear?

   c. A mechanism not yet defined?

   d. A combination of a, b, and c?

Frosted and not-frosted samples of Air Force Blue uniform fabrics made from polyester/wool [illegible] [illegible]. Tools of investigation will be the optical microscope, the scanning electron microscope, the X-ray fluorescence spectra microprobe supplemented by other chemical and physical analysis techniques as needed.

In addition fabrics made from 100% polyester, 100% wool, and blends of polyester and wool (~50/50) will be dyed and finished, abraded under controlled conditions, and examined in order to arrive at the answer to the above questions.

There are many factors which will influence the magnitude of the frosting of polyester/wool fabrics, but it is believed that the basic mechanism(s) will be the same regardless of the polyester type provided reasonable processing procedures are used in making the fabrics.

B. Factors Which Alter the Magnitude of the Change in Appearance (Frosting) Due to Wear

The following factors which may alter the degree of frosting, fabric drape, and processibility.

1. Chemical type of polyester
2. Percent polyester in blend
3. Denier of polyester fiber and grade of wool
4. Yarn and fabric construction
5. Chemical processing of both polyester and wool, i.e., chemical damage to fibers during processing, poor dye penetration, etc.
6. Effect of dry-cleaning and steam-pressing

It is hoped that the fiber and textile manufacturers can throw considerable light on the importance of these factors in frosting.

C. Choice of Polyester Fiber for Application in Uniform Fabrics

Polyester fibers with modified dyeing and abrasion properties introduced in recent years will be evaluated for their performance. The assistance of the various fiber manufacturers has been solicited to expedite this part of the program.

D. Development of Optimum Dyeing Formulations and Finishing Procedures

1. Review of current practice in finishing polyester/wool blend fabrics.

2. Selection of dyes and the generation of starting dye formulations for wool and polyester.

3. Preparation of dyed fabrics by several dyeing and finishing procedures and their evaluation for wear, frosting, drape, processibility. (This will include both stock and piece dyeing procedures.)

4. Establishment of optimum dye formulations.

5. Scale-up to pilot dyeing procedures (five-yard pieces, and ten-pound stock dyeing).

E. Fiber Processing and Fabric Design

This phase of the program involves an investigation of fabric construction parameters and fiber processing procedures which may provide some improvement in fabric performance, specifically, improve abrasion resistance to frosting, drape, sewability and processibility. These include:

1. 70's grade wool versus 64's grade wool

2. Type of polyester (three will be considered)

3. Fiber blend homogeneity

   a. Number of gillings

   b. Core-spun yarn versus intimate blend

4. Relative amounts of wool and polyester fiber in blend

5. Combing

6. Yarn and ply twist levels

7. Degree of fulling

F. Delivery of Experimental Fabrics to the Air Force

Experimental fabrics generated during the course of this program will be delivered to the Air Force for sewability, drapeability, and tailoring evaluations. Five yard pieces, 39" wide will be supplied.

Subsequent to the complete evaluation of all the results in the above outlined study and with the concurrence of the Air Force program project engineer, six fabrics will be chosen for field testing. Three of the fabrics should exhibit improved properties at comparable cost to present fabric and the other three, greatly improved properties at a moderate increase in cost. Five hundred yards of each fabric will be woven and supplied to the Clothing Branch, Aeronautical Systems Division for fabrication of uniforms to be used in the three year service test.

The processing procedures used to produce each fabric, the fabric construction and fabric properties will be given in detail to insure that the fabric can be reproduced at a future date and also to supply sufficient data for preparation of fabric specifications.

III. Progress Report

A. Study of Worn Air Force Uniform Fabric

a. Optical microscopic and scanning electronmicroscopic examination of worn and unworn fabric.

b. Examination of fabric after removal of wool component.

c. Examination of fabric after treatment to remove polyester component.

B. Discussion with Manufacturers of Polyester Fibers

C. Discussion with Manufacturers of Dyes and Finishing Auxiliaries.

IV. Specific Questions for Discussion with Representatives of Textile Manufacturers

A. Which polyester fiber gives the best frosting performance in blends with wool?

B. Is stock (or top) dyeing of the two fibers individually preferred to piece dyeing? Why?

C. What are their views on the mechanism(s) of frosting?

D. What factors in processing alter the magnitude of frosting?

E. Has a study been made of the effect of dry cleaning on the wear of polyester/wool blend fabrics?

F. What difficulties are encountered in producing solidity of shade in the fabric, i.e., matching under different light sources?

G. What are the advantages of carbonizing in the piece?

H. What special textile auxiliaries have proved to be useful in minimized frosting?

I. What factors in yarn and fabric construction appear to be important?

J. P. Stevens & Co., Inc.

STEVENS TOWER, 1185 AVENUE OF THE AMERICAS, NEW YORK, N.Y. 10036

ndor W. Anthony
ice President

November 3, 1972

Mr. Jack H. Ross CODE: MBC
Air Force Materiel Laboratory
Wright Patterson Air Force Base
Dayton, Ohio

Dear Jack:

In our telephone conversation this morning, we explored why we reluctantly turned down the invitation from the Georgia Institute of Technology to participate in their long range contract #F33615-72-C-1822 consisting of "exploratory development on polyester/wool uniform fabrics with improved durability and appearance".

Our reasons, of course, are obvious. We no longer are in the worsted business as of approximately three months ago and as I mentioned over the 'phone, have gone so far as to convert our last remaining worsted mill over to a cotton mill making bed sheeting and pillow case fabrics.

All of the above is a matter of record but more importantly, I believe that the Air Force should call for an accurate intensive industrial mobilization survey of what is left of the worsted producing industry capable of making this category of Class A uniform fabrics, which embraces not only your fabric but the same fabric as is used by the Army and the Marine Corps [illegible] in its respective color.

Frankly, we believe that a factual accurate industrial mobilization survey will disclose that there just is not the capability left to supply any large scale purchases by the military without taking into consideration the availability of goods for the civilian economy.

atch 1

J. P. Stevens & Co. Inc.

Mr. Jack H. Ross
Wright Patterson Air Force Base -2- November 3, 1972

Unfortunately, the industrial mobilization surveys are not mandatory and required of every mill in the country but more importantly, they are conducted on a once every twelve or eighteen month basis. You know as well as I that in any twelve month period, with an industry as volatile and changeable as the textile industry, product changes can take place in a manufacturing unit that would not be spotted for some ten or fourteen months later. Believe me, these changes are and have been taking place with unbelievable rapidity and I doubt that anyone could devise an industrial mobilization survey that could keep pace with this rapid change.

Just in closing, an up-to-date study of the raw wool market and its availability at today's pricing would likewise shock and dismay you.

This whole subject of the decline in the United States woolen and worsted industry, brought about mainly by foreign imports, is an old story but it has finally come home to roost and I urge you to investigate it.

Yours sincerely,

Alexander W. Anthony
Vice President

AWA:hgp

Burlington Worsteds

A division of Burlington Industries

Research and Development Center
P. O. Box 788
Clarksville, Virginia 23927
(703) 374-8111

October 16, 1972

Mr. Milton W. Bennett
Assistant Director
Georgia Institute of Technology
Office of Research Administration
Atlanta, Georgia 30332

Dear Mr. Bennett:

This is to acknowledge receipt of your letter of October 6 in which you requested Burlington Industries to provide consultant assistance to Georgia Tech for Air Force Development Contract #F33615-72-C-1822.

In view of our division's recent product mix changes to completely new fabrications, both in wovens and knits involving new fibers and yarns coupled with a change in organizational structure, it will not be possible for us to provide the technical personnel to assist Georgia Tech on this contract.

Am sure you can appreciate the major problems that we are facing where we have completely changed to new fabrications, and the involvements thereof present technical problems of major consequence which precludes re-assignment to other projects even of short duration as described in your letter and attached work statement to Textile Manufacturers.

Our very best wishes to you on this development contract. With kindest regards.

Yours very truly,

Marvin J. Pinson, Jr.
Vice President - Product Development

MJP:hc

cc: Dr. Denny Freston
Dr. [illegible]

J.P. Stevens & Co., Inc.

TECHNICAL CENTER

141 LANZA AVENUE • GARFIELD, NEW JERSEY 07026 • AREA CODE 201 • 772-7100

Frank X. Werber, Vice President
Research and Development

November 1, 1972

Mr. Milton W. Bennett
Assistant Director
Georgia Institute of Technology
Office of Research Administration
Atlanta, Georgia 30332

Dear Mr. Bennett: Subject: Request for Proposal (E-27-613)

I am sorry to be so long in replying to your letter of October 6th (received October 17th). We have considered carefully your invitation to submit a proposal and regret to inform you that we have come to a negative decision.

Our decision was based on thorough study of your work statement. Although we still have personnel familiar with the general problems of the worsted business, and polyester/wool blends specifically, we would be in no position to work with your people in manufacturing facilities of our own or to carry through our suggestions, and your results, in manufacturing facilities under our control.

We have the highest respect for your faculty people charged with this program, and hope that we will have a chance to work with them on other matters in the future. I am sorry that this had to be our conclusion for the present.

Sincerely,

FXWerber

F. X. Werber

FXW/eg

cc: Dr. W. Denny Freeston
Dr. Walter C. Carter

E-27-613

Interim Technical Report Number 2

(15 November 1972 to 15 May 1973)

Exploratory Development of Polyester/Wool Uniform Fabric with Improved Durability and Appearance

Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

(Prepared under Contract No. F33615-72-C1822 by
Georgia Institute of Technology, Atlanta, Georgia,
A. J. Maguire and W. C. Carter, Authors)

Abstract

An evaluation of the abrasion resistance of wool and four (4) polyester single filaments and the effect of the dyeing process on abrasion resistance has been completed. The abrasion resistance of wool was found to be poor relative to that of polyester fibers. The polyester fibers studied have been ranked with respect to their abrasion resistance. There is a deterioration in abrasion resistance due to the dyeing process. Those variables in the dyeing process which affect tensile properties and abrasion resistance have also been established.

Dyes recommended for application to wool and polyester fibers are included in this report. Dye formulations and dyeing procedures have been established for use in the production of experimental fabrics.

A program to determine the effect of the major variables in the composition, structure, and processing conditions used in making uniform fabrics on abrasion resistance is described. The experimental fabrics which will result from this program are expected to be available for evaluation 15 August, 1973.

Table of Contents

I. Introduction

In the Interim Technical Report No. 1, for the period 15 May to 15 November, 1972, a detailed description of work to determine the nature of the frosting problem as related to worsted polyester/ wool uniform fabrics was described. Based on the results of this work, polyester fibers representing variations in chemical composition and physical structure and properties were chosen for further investigation, with the expectation that it would be possible to relate their abrasion resistance and thus "frosting" tendency to specific fiber properties and structural parameters - important in abrasion.

This report includes:

1) an evaluation of the abrasion resistance of four commercially available polyester fibers and the effect of the dyeing process on their abrasion resistance.

2) a study of variables in the dyeing of polyester fiber and their effect on its mechanical properties and the depths of shade achieved.

3) a description of an experimental design to delineate effects of variables in the composition and structure of polyester/ wool fabrics on abrasion resistance. The status of this experiment is also given.

II. Selection and Properties of Polyester Fibers

Based on a knowledge of those polyester fibers in current use in the manufacture of worsted fabrics, particularly uniform fabrics, and with a limited knowledge of their properties and structural parameters as they relate to abrasion resistance, four commercially available types were chosen for study, namely,

Dacron type 54
Dacron type 64
Dacron type 35
Dacron type 59

Although these fibers are made by one manufacturer, namely E. I. duPont de Nemours and Company, they represent variations in chemical composition, molecular weight, and stress-strain behavior typical of other commercially available polyester fibers.

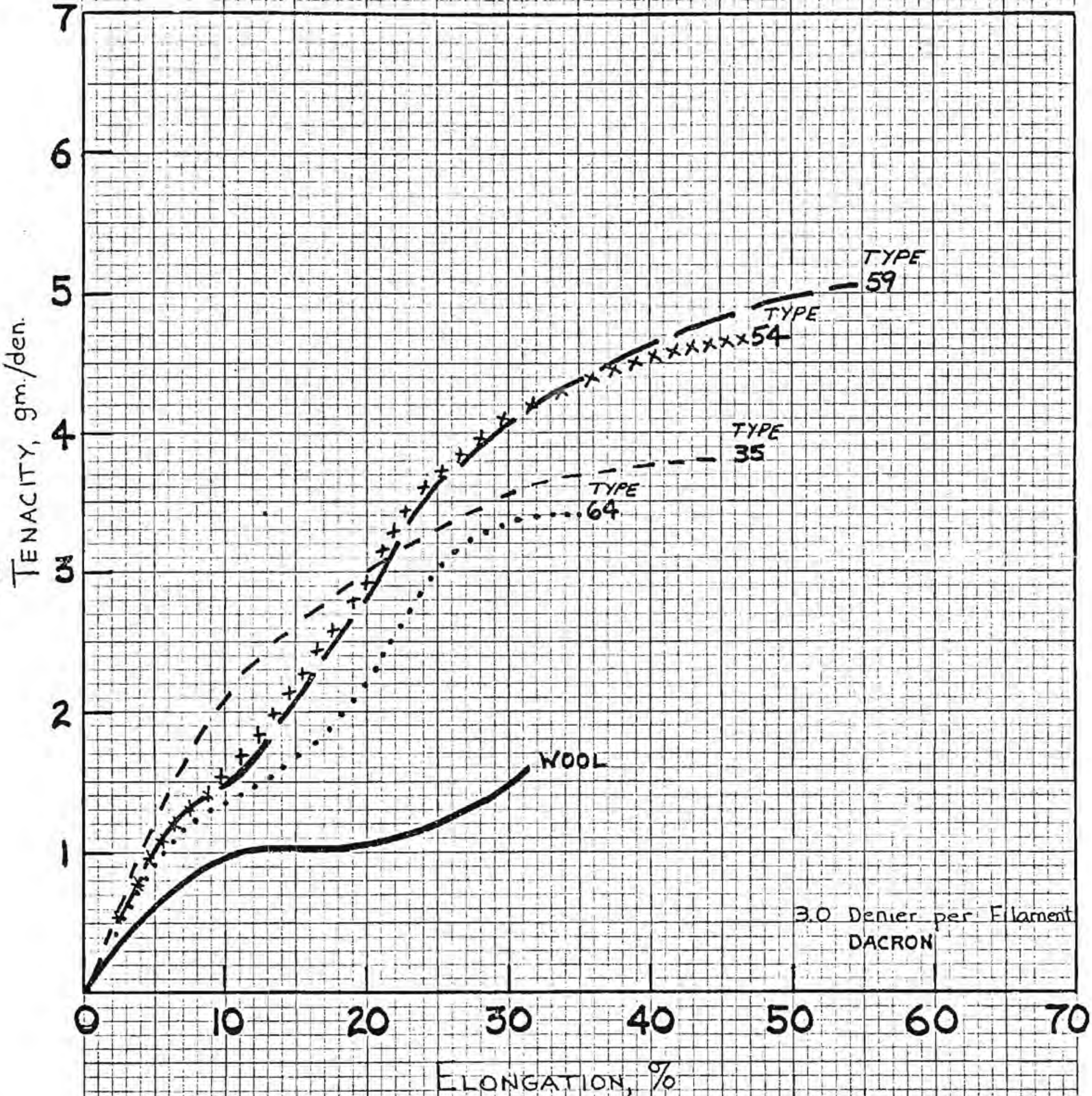
A. Stress Strain Behavior and Effect of Dyeing on Stress Strain Behavior and Single Fiber Abrasion

The stress-strain curves for the four polyester fibers chosen for this work are shown in Figure 1. Properties derived from these curves are given in Table I.

TABLE I
Tensile Properties of Polyester Fibers

Fiber	Elongation at Break %	Breaking* Load (gm-wt)	Initial Modulus (g/den)	Energy to* Rupture (gm-wt-cm)
Dacron 54	43	14.9	29	3.1
Dacron 64	41	10.1	26	1.7
Dacron 35	44	10.5	47	3.3
Dacron 59	55	15.3	28	5.1

*For 3.0 denier filaments



7
6
5
4
3
2
1
0
10
20
30
40
50
60
70
TENACITY, gm./den.
ELONGATION, %
TYPE 59
TYPE 54
TYPE 35
TYPE 64
WOOL
3.0 Denier per Filament
DACRON

FIGURE 1

The abrasion behavior of these fibers was determined using a fatigue apparatus capable of abrading single fibers under normal loads approximating those involved in standard flat-abrasion tests and speeds up to 1800 cycles per minute. The fibers were abraded against a tungsten wire (~ 8 mil diameter), the normal load being 200 mg. The fibers were abraded from one to ten hours (30 cycles/ sec) and then examined by scanning electron and light microscopy. Noticeable damage to all fibers was obtained after one hour of abrasion. Although the extent of damage increased with increasing time of abrasion, the damage after ten hours was not as great as would be expected considering the damage after one hour probably due to the decrease in the force per unit area exerted on the filament by the abrading wire as the damage increases. It was concluded that an abrasion time of two hours was sufficient to estimate how the fibers were wearing relative to one another. The decreasing order of abrasion resistance was found to be Dacron 35 = Dacron 54 > Dacron 59 > Dacron 64. Dacron 64 stands out as having a much poorer abrasion resistance than the other fibers. Dacron 35 and Dacron 54 were very similar in abrasion resistance. Attempts have been made to relate the abrasion resistance to mechanical properties, primarily initial modulus and energy to break. There is no clear relationship; however, the order of abrasion resistance does correlate with the energy to yield, decreasing as the energy to yield decreases. The very low energy to break for Dacron 64 probably accounts for its poor abrasion resistance.

Of more importance than the mechanical properties and abrasion resistance of the undyed, unfinished fiber as described above are the properties of the fibers after they have been dyed since it is in this state that the fibers exist in a uniform fabric. Therefore, the abrasion resistance was determined for Dacron 54 and Dacron 64 fibers which had been dyed. These two fibers were chosen because they represent extremes in abrasion resistance and also because they are believed to be the two fibers in common use for making uniform fabrics. Two dyeing temperature ranges were employed, namely 125-135°C (pressure dyeing) and 95-100°C (atmospheric dyeing). These ranges are typically those used in dyeing polyester fibers.

Pressure Dyeing

1. 3% Carrier o.w.f. (Cindye DAC-888)
   Dyeing temperature 125°C
   Dyeing time 60 min.

2. 3% Carrier o.w.f. (Cindye DAC-888)
   Dyeing temperature 135°C
   Dyeing time 60 min.

Atmospheric Dyeing

Variables:

Dyeing temperatures 95°C and 100°C

Dyeing times 120 min. and 150 min.

Carrier - Cindye DAC-888 - 10.0 and 11.0% o.w.f.

The fibers dyed under pressure were found to be slightly less abrasion resistant than the undyed fibers with Dacron 64 showing more loss in abrasion resistance than Dacron 54.

The tensile properties of the dyed fibers which were abraded are shown in Table II.

TABLE II

Effect of Dyeing on Tensile Properties
(3-denier staple)

	Breaking Strength (g)	Breaking Elongation (%)	Work to Rupture (g-cm)	Initial Modulus (g/den)
Dacron 54				
Undyed	14.9	43	3.1	29
Dyed 125°C*	15.2	39	2.5	37
Dyed 135°C*	15.0	39	1.9	34
Dacron 64				
Undyed	10.1	41	1.7	26
Dyed 125°C*	9.8	29	1.1	32
Dyed 125°C*	10.6	31	1.2	33

*3.0% Carrier, 60 min.

The fibers dyed under atmospheric dyeing conditions also were poorer in abrasion resistance than the undyed fibers with Dacron 64 being poorer than Dacron 54. The most important factor in dyeing on abrasion resistance was found to be the amount of carrier employed, decreasing with increasing amounts of carrier used.

It is concluded from this work that the abrasion resistance of polyester fibers is reduced by dyeing. The severity of the dyeing conditions will determine the magnitude of the loss in abrasion resistance, e.g. too high a dyeing temperature, extended times of dyeing, and excessive amounts of carrier. The loss in abrasion resistance noted indicates that redyeing due to off-shades will only lead to a further decrease in abrasion resistance and should never be done if one is to obtain optimum abrasion resistance.

The conditions used in abrading polyester fibers, namely 30 cycles/sec, 2 hours, with a normal force of 200 mg, could not be used to evaluate wool fibers due to their poorer abrasion resistance. Therefore, the time of abrasion was reduced to fifteen minutes. Eight wool fibers, 64's Grade, were abraded and only five fibers survived. Microscopically it is apparent that approximately one-half of the fiber was abraded away.

It is expected that the observed single filament abrasion behavior of wool and the polyester fibers will be translated to the blend uniform fabric. Confirmation of this will be discovered when the abrasion properties of the experimental fabrics have been determined.

III. Dyeing Procedures for Wool and Polyester Fibers

A. Selection of Dyes

In order to achieve the Air Force Blue 1549 Shade on both polyester and wool fibers which meets the standards of color specification and fastness requirements, careful selection of dyes is required. Most types of polyester fibers can be dyed only with disperse dyes. Those fibers such as Dacron 64 which contain acid sites can be dyed with cationic dyes; however, the light fastness of these dyes is not sufficient to meet the requirements for the Air Force fabric. The wool component can be dyed with acid dyes including all types of acid dyes (leveling acid, neutral dyeing milling, acid metallized, and neutral dyeing metallized, and chrome). As in the care of dyeing polyester, careful selection of dyes is required to meet the color standard and fastness properties. The dyes which have been investigated and found suitable for application are given in Tables III and IV.

It should be noted that one manufacturer, General Aniline and Film, recommended a wool dye which is a stable leuco vat ester, namely Algosol Blue 0. No work has been done with this dye.

Data has been accumulated for all of the dyes listed in Tables III and IV including spectral data for two concentrations of each dye and their light fastness.

Laboratory dyeings have been made on Dacron 54 and Dacron 64 using a pressure dyeing procedure at 125°C and dyeing formulations recommended by General Aniline and Film, Sandoz, and duPont.

The color differences between these dyeings and the Air Force Standard are shown in Figure 2 as total lightness difference (ΔL)

TABLE III

Disperse Dyes for Polyester Fiber

Name	C. I. Name	Manufacturer*
Foron Blue E-R	Disperse Blue 20	S
Foron Rubine SE-GLF	Disperse Red 73	S
Foron Yellow E-RGFL	Disperse Yellow 23	S
Resolin Blue FBL	Disperse Blue 56	V
Resolin Red BRL	Disperse Red 134	V
Resolin Orange 3GL	Disperse Orange 66	V
Eastman Poly Blue GLF	Disperse Blue 27	ECP
Eastman Poly Blue BLF	Disperse Blue 120	ECP
Eastman Poly Blue 4RL	Disperse Blue 64	ECP
Eastman Poly Red FFBL	Disperse Red 60	ECP
Eastman Poly Yellow G-LSW	No Listing	ECP
Genacron Blue BGL	Disperse Blue 120	GAF
Genacron Cerise B	Disperse Red 59	GAF
Genacron Yellow GGLL	Disperse Yellow 48	GAF
Latyl Blue LS	Disperse Blue 62	DUP
Latyl Brill. Blue BG	Disperse Blue 60	DUP
Latyl Violet BN	Disperse Violet 27	DUP
Latyl Cerise B	Disperse Red 59	DUP
Latyl Yellow YLW	Disperse Yellow 42	DUP
Latyl Violet 2R	Disperse Violet 18	DUP

*S - Sandoz
V - Verona
ECP - Eastman Chemical Products
DUP - duPont
GAF - General Aniline and Film

TABLE IV

Dyes for Wool

Name	C.I. Name	Manufacturer*
Levelan Navy Blue IRL	No Listing	V
Levanol Brilliant Blue FFG	Acid Blue.....	V
Isolan Orange R	....	V
Isolan Yellow NW	Acid Yellow	V
Acid Chrome Blue RRA	Mord. Blue 9	GAF
Metamega Chrome Cyanini BLL	Mord. Blue 7	S
Omega Chrome Black Blue G	No Listing	S
Metomega Chrome Bordeaux 2BL (Pat)	No Listing	S
Metomega Chrome Yellow ME	No Listing	S

* V - Verona
GAF - General Aniline and Film
S - Sandoz

and total color difference (ΔE) with both ΔL and ΔE being expressed in MacAdams units. With the exception of a duPont formulation on Dacron 54, all dyeings were darker (ΔL) than the Air Force Standard. The chromaticity differences (ΔC), not shown in Figure 2 contribute negligibly to the overall color differences (ΔE). These results show that dyeing formulations can be readily adjusted to duplicate the Air Force Standard. It is further concluded that dye formulations can be easily developed which preclude the use of small, "pinch" quantities of any one component of the dye formulation.

B. Effect of Dyeing Conditions on the Color Yield and Tensile Properties of Polyester Fibers

1. Dyeing Conditions and Color Yield

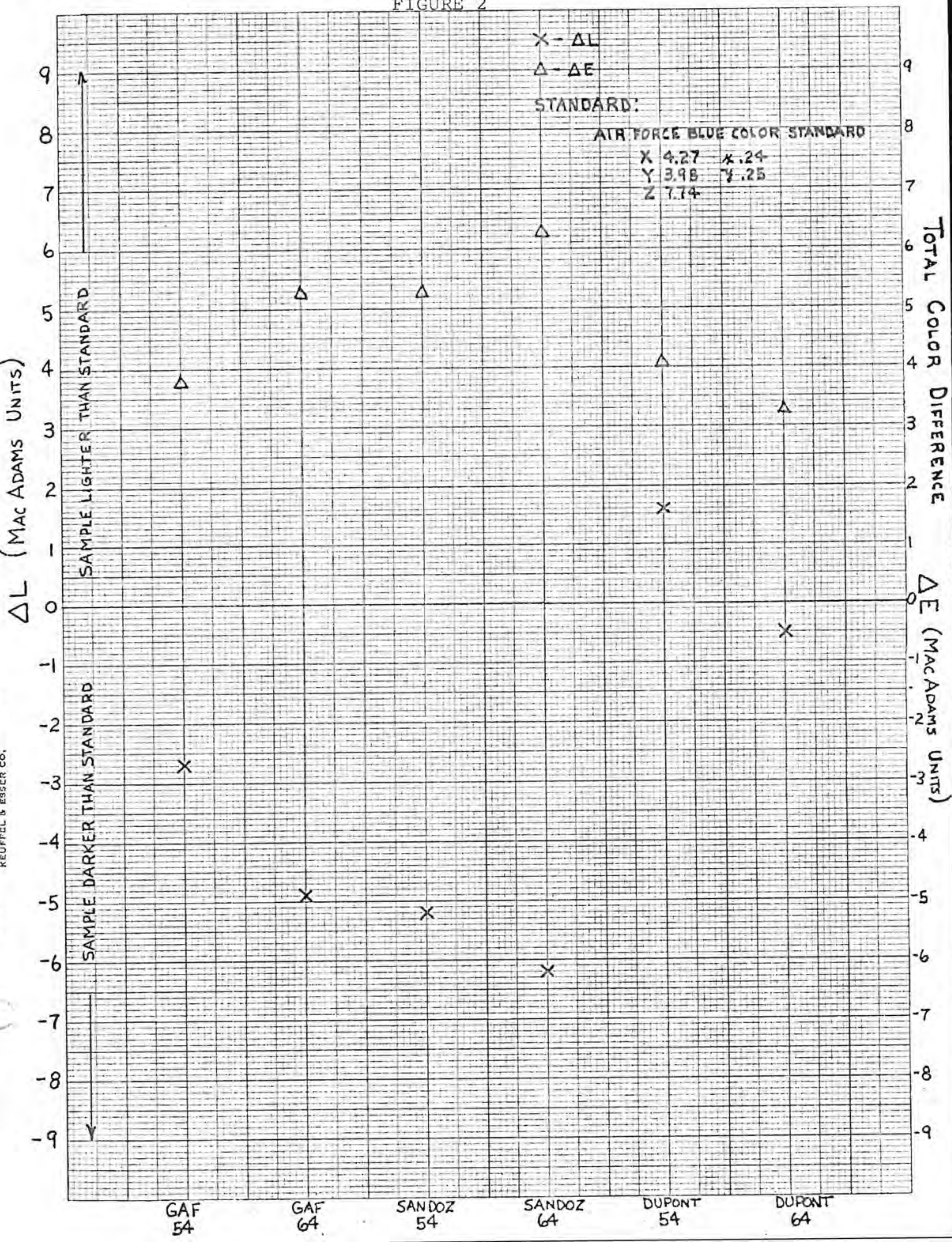
In the dyeing of polyester fibers, two alternative dyeing procedures are usually employed:

1) Atmospheric dyeing at a temperature of approximately 100°C with the use of dyeing "carriers" in amounts from 10 to 15 percent based on the weight of fiber to be dyed.

2) Pressure dyeing at a temperature of 120° to 135°C either with no dyeing carrier or approximately 3 percent based on the weight of fiber to be dyed.

The latter procedure is preferred because of shorter dyeing cycles but there is the requirement of dyeing equipment which can be pressurized. Many dyehouses do not possess this equipment. The variables which affect color yields and mechanical properties are the dyeing temperature, dyeing time, and the amount of carrier used, deterioration in polyester fiber properties increasing with increases in each of these variables.

FIGURE 2


X - ΔL
Δ - ΔE
STANDARD:
AIR FORCE BLUE COLOR STANDARD
X 4.27 x .24
Y 3.98 y .25
Z 7.74
ΔL (MAC ADAMS UNITS)
SAMPLE LIGHTER THAN STANDARD
SAMPLE DARKER THAN STANDARD
TOTAL COLOR DIFFERENCE
ΔE (MAC ADAMS UNITS)
GAF 54
GAF 64
SANDOZ 54
SANDOZ 64
DUPONT 54
DUPONT 64

In this study, a disperse dye typical of the blue component in the Air Force Blue 1549 shade, namely Latyl Blue, was chosen. The assumption is that the other dyes necessary for producing the Air Force shade will behave similarly.

The following conditions were used:

Atmospheric Dyeing

Temperature °C	95°, 100°
% Carrier (based on fiber weight)	9.0, 10.0, 11.0
Dyeing time (min.)	60, 120, 150

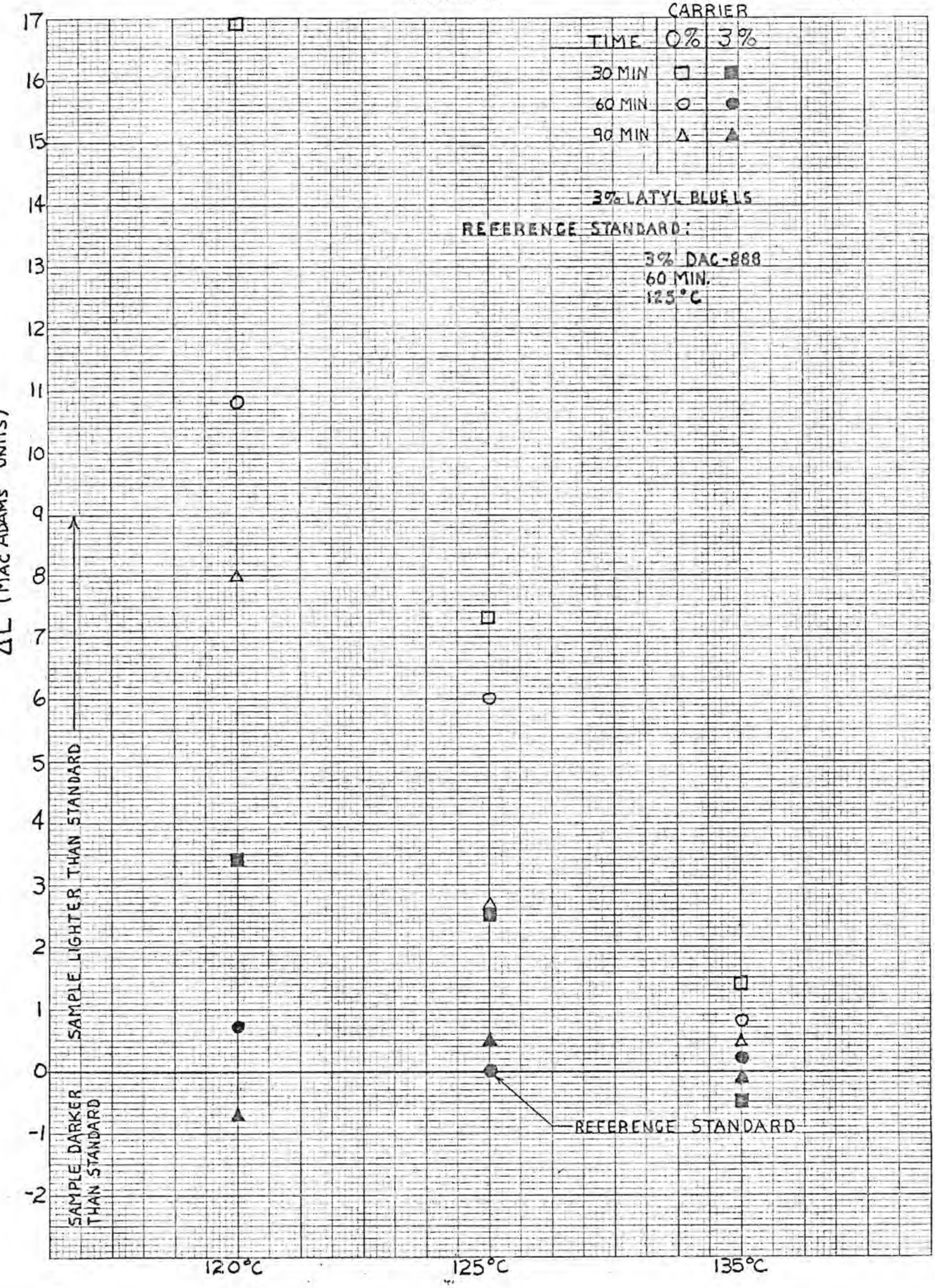
Pressure Dyeing

Temperature °C	120°, 125°, 135°
% Carrier (based on fiber weight)	0.0, 3.0
Dyeing time (min.)	30, 60, 90

The carrier used in these dyeings is Cindye DAC-888, a butylbenzoate carrier sold by Cindet Chemicals, Inc., and recommended for both atmospheric and pressure dyeing of polyester fibers. It should be noted that the experiments for atmospheric and pressure dyeing are factorially designed (3 x 3 x 2) making possible a statistical treatment of the responses.

For the dyeings made under pressure, the variation in color yield with variations in dyeing time, dyeing temperature and carrier is shown in Figure 3. Total lightness difference (ΔL), expressed in MacAdams units, is plotted in Figure 3 since any color differences are due primarily to lightness differences. All dyeings are compared with a standard dyeing, namely, 125°C, 60 min., 3.0% carrier. Figure 3 shows clearly that the effect of time and temperature of dyeing on color yields is much smaller in the presence of carrier than when no carrier is used. Statistical treatment of the color data showed that

FIGURE 3



CARRIER
TIME 0% 3%
30 MIN
60 MIN
90 MIN
3% LATYL BLUE LS
REFERENCE STANDARD:
3% DAC-888
60 MIN.
125°C
ΔL (MAC ADAMS UNITS)
SAMPLE LIGHTER THAN STANDARD
SAMPLE DARKER THAN STANDARD
REFERENCE STANDARD
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
120°C
125°C
135°C

the most important factors affecting color yield were the carrier and dyeing temperature. The interaction of these two factors was also found to be important. The following alternate procedures are recommended:

1) 3.0% carrier (DAC-888)
   120°C
   90 min.

2) 3.0% carrier (DAC-888)
   125°C
   60 min.

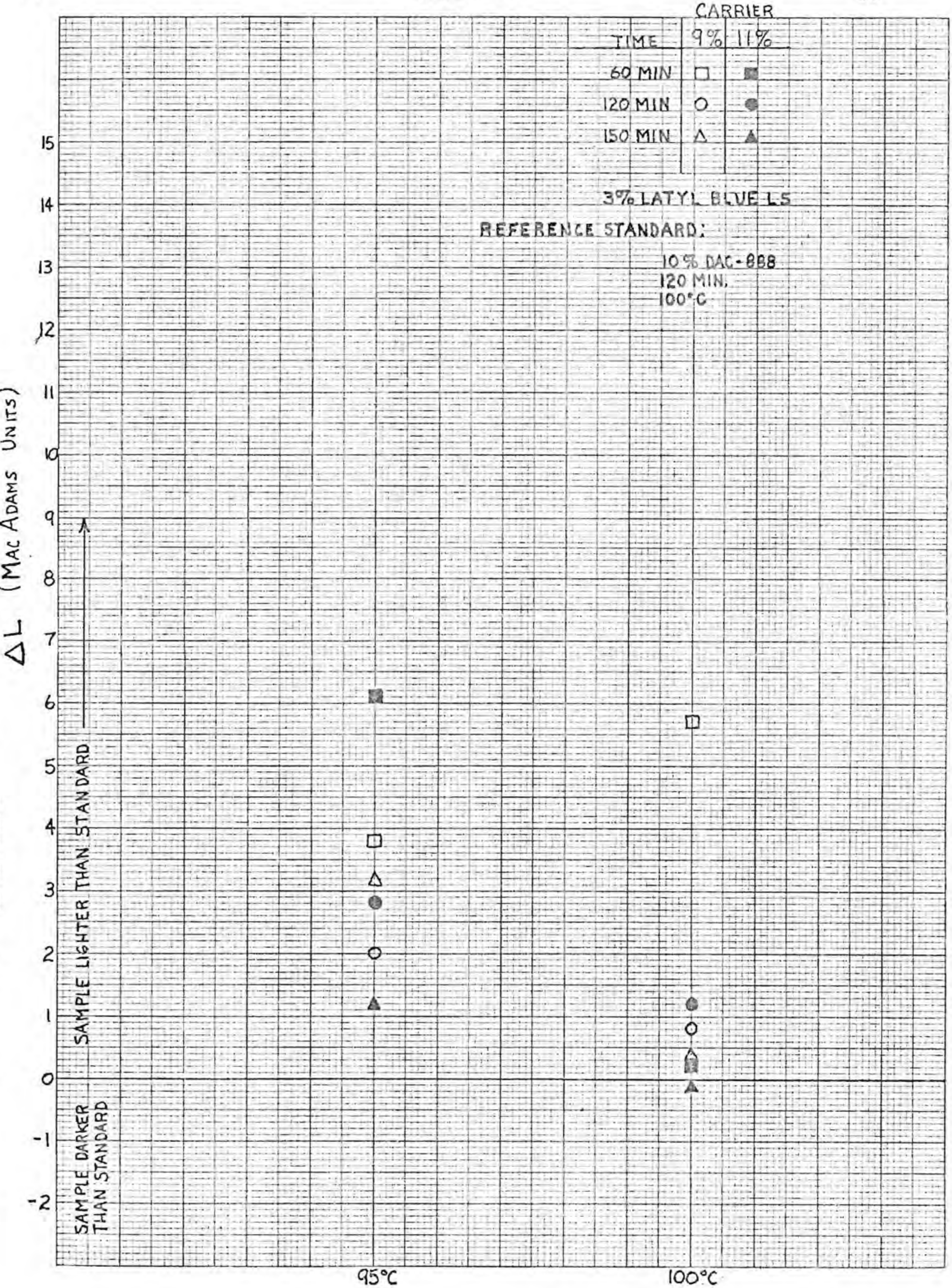
For atmospheric dyeings made at 95° and 100°C, the reference dyeing to establish the effect of carrier, temperature and time of dyeing on color yields, was 100°C, 10% carrier, 120 min. The results are shown in Figure 4. It can be seen that all of the dyeings carried out at 95°C are 1-6 MacAdams units lighter than the standard reference while most of those carried out at 100°C closely approximate the results obtained under the dyeing conditions used for the standard. A statistical treatment of the data shows that within the practical dyeing limits in the experimental design, the only significant factor affecting color yield was the dyeing temperature.

The dyeings made under atmospheric conditions, 95° and 100°C, were found to be approximately four MacAdams units lighter (ΔL) than those made under pressure (120°, 125°, 135°C). This means that dyeings made under atmospheric conditions will require approximately ten (10) percent more dye than those under pressure to arrive at equivalent shades.

2. Dyeing Conditions and Tensile Properties

The tensile properties have been determined for both Dacron 54 and Dacron 64 dyed under the pressure dyeing conditions described

FIGURE 4


CARRIER
TIME
9%
11%
60 MIN
120 MIN
150 MIN
3% LATYL BLUE LS
REFERENCE STANDARD:
10% DAC-888
120 MIN.
100°C
ΔL (MAC ADAMS UNITS)
SAMPLE LIGHTER THAN STANDARD
SAMPLE DARKER THAN STANDARD
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
95°C
100°C
KEUFFEL & ESSER CO.
MADE IN U.S.A.

above. The results are shown in Table V.

Inspection of the data shows clearly that both fibers exhibit an appreciable loss in work to rupture (30 to 40% loss) as a result of dyeing. The dyed Dacron 54 has a work to rupture approximately twice that of the dyed Dacron 64. This ratio of 2 to 1 is also shown by the undyed fibers.

Both dyed fibers have lower elongations at break than the undyed fiber, being more pronounced with Dacron 64. Slight increases in modulus were noted for both fibers. A statistical analysis of the breaking load data shown that the interaction of the factors, percent carrier and dyeing temperature, was significant in the 99% confidence level. Thus, an increase in the dyeing temperature coupled with an increase in the amount of carrier leads to a decrease in the breaking load.

No tensile properties have been determined for fibers dyed under atmospheric conditions; however, the abrasion properties have been measured and described in Section II of this report.

C. Development of Dyeing Formulations and Procedures for Application in Making Experimental Fabrics

Dyeing formulations and procedures for both wool and all types of polyester fiber involved in the experimental fabric program have been established. The dye formulation and procedure for wool is being used by Florence Dye Works. This company already had in hand a formulation and procedure for dyeing the polyester fibers. These were examined by Georgia Tech personnel and it was mutually agreed that their dye formulation and procedure were essentially comparable to those developed at Georgia Tech and completely satisfactory for the production of the experimental fabrics.

TABLE V

Effect of Dyeing Conditions on Tensile Properties of Polyester Fibers

Treatment			Dacron 54				Dacron 64			
			Breaking Strength (g)	Breaking Elongation (%)	Work to Rupture (g-cm)	Initial Modulus (g/den)	Breaking Strength (g)	Breaking Elongation (%)	Work to Rupture (g-cm)	Initial Modulus (g/den)
Before Dyeing			14.9	43	3.1	29	10.1	41	1.7	26
After Dyeing T°C	Time (min)	Carrier (%)								
120	30	0	15.5	41	2.4	30	9.7	26	1.0	34
120	30	3	14.2	34	1.8	39	10.2	33	1.5	33
120	60	0	13.7	35	1.8	32	9.5	31	1.2	31
120	60	3	14.8	46	3.2	30	10.4	28	1.1	36
120	90	0	14.9	33	1.8	30	9.9	30	1.2	30
120	90	3	12.9	36	1.5	27	9.3	29	1.1	30
125	30	0	13.7	40	2.4	27	10.0	32	1.0	27
125	30	3	15.6	41	2.7	33	9.9	28	1.1	32
125	60	0	14.1	38	2.1	29	9.0	29	0.8	25
125	60	3	15.2	39	2.5	37	9.8	29	1.1	32
125	90	0	13.9	33	1.6	44	8.2	25	0.7	28
125	90	3	16.8	41	2.7	35	9.8	28	1.0	33
135	30	0	14.7	37	1.6	34	8.3	27	1.0	37
135	30	3	15.3	41	3.0	34	9.5	29	1.0	39
135	60	0	14.7	38	2.6	38	9.9	29	1.1	33
135	60	3	15.0	39	1.9	34	10.6	31	1.2	35
135	90	0	14.6	36	1.4	36	9.7	31	1.2	29
135	90	3	15.8	39	2.9	34	8.6	27	0.9	30

IV. Experiment to Delineate Effects of Variables in the Composition and Structure of Polyester/Wool Uniform Fabrics on Abrasion Resistance

The design of an experiment to sort out the effect of variables in the production of polyester/wool uniform fabrics on their abrasion resistance is based on information obtained from several sources:

1) Discussions with fiber and textile manufacturers, as well as manufacturers of dyes and dyeing assistants.

2) Technical information available from fiber manufacturers.

3) Literature in technical journals related to fiber and fabric abrasion (pilling and frosting).

4) Work conducted in this program.

The initial design described in the Bimonthly Technical Report Number 3 for the period 15 November, 1972 to 15 January, 1973 was modified following receiving valuable input from those textile manufacturers who are providing the services necessary for the production of the experimental fabrics. The final design is described in the Bimonthly Technical Report Number 4 for the period 15 January, 1973 to 15 March, 1973 and is included below in this report.

Following a thorough examination of the possible factors contributing to abrasion resistance, it was concluded that the variables which should be investigated in a statistically designed experiment are as follows:

1) Polyester type

2) Grade of wool

3) Cabonization

4) Relative amounts of wool and polyester in blend

5) Yarn twist

6) Denier of polyester fiber.

To minimize the number of fabrics required for this experiment, it was decided that the basic design would be a 2^5 design, the five variables being the first five listed above at two levels for each variable. A fractional factorial experiment (5 factors in 8 observations) are being performed, i.e. eight (8) fabrics. The production of four additional fabrics will make possible an evaluation of an additional level for variable 1 (polyester type) and variable 5 (yarn twist) as well as an evaluation of the effect of the denier of the polyester fiber on abrasion.

The variables and levels for each variable arranged in decreasing order of their estimated importance in abrasion are as follows.

Variable	Level –	Level +
A. Polyester Type (3 denier)	Dacron 64	Dacron 54
B. Grade of Wool (Domestic)	64's	64-70's
C. Carbonizing	yes	no
D. Composition of Blend - Polyester/Wool	60/40	40/60
E. Yarn Twist (t.p.i.)	12	15

The experiments to be performed are described below:

Fractional Factorial for 2^5 Design (1/4 replicate)

EQUATE D to ABC
E to -BC

	A	B	C	D	E	Treat. Comb.	Effects and Aliases
Y_1	-	-	-	-	-	1	A, -DE
Y_2	+	-	-	+	-	ad	B, -CE
Y_3	-	+	-	+	+	bde	C, -BE
Y_4	+	+	-	-	+	abe	D, -AE
Y_5	-	-	+	+	+	cde	E, -BC, -AD
Y_6	+	-	+	-	+	ace	AB, CD
Y_7	-	+	+	-	-	bc	AC, BD
Y_8	+	+	+	+	-	abcd	

$D(D=ABC) = (D^2=ABCD) = (I=ABCD)$

$E(E=-BC) = (E^2=-BCE) = (I=-BCE)$

$(ABCD)(-BCE) = -ADE$

defining contrasts I, ABCD, -BCE, -ADE

aliases - (i) A, BCD, -ACE, -DE
(ii) B, ACD, -CE, -ABDE
(iii) C, ABD, -BE, -ACDE
(iv) D, ABC, -BCDE, -AF
(v) E, ABCDE, -BC, -AD
(vi) AB, CD, -ACE, -BDE
(vii) AC, BD, -ABE, -CDE

Notes:

1) In order to obtain additional information concerning the effect of yarn twist, the composition corresponding to Y_6 in the design will be converted to two additional fabrics in which the yarn twist will be 12 tpi and 18 tpi.

2) In order to determine the effect of polyester denier, an additional fabric will be prepared in which a 4.5 denier Dacron 54 will replace the 3.0 denier Dacron 54 in the sample described as Y_6.

3) It would be desirable to evaluate another polyester fiber, whose properties differ from those of Dacron 54 and Dacron 64. To accomplish this, a fabric sample will be prepared in which 3.0 denier Dacron 35 replaces the 3.0 denier Dacron 54 in the sample described as Y_6.

In summary, ten different blended polyester/wool tops are being prepared from which twelve sample fabrics will be made. Flow diagrams for the production of the sample fabrics are shown in Figures 5, 6, 7.

The companies supplying the necessary services for producing the sample fabrics are as follows:

1) Source of wool tops and polyester tops:

Wellman, Incorporated
Johnsonville, South Carolina

2) Dyeing and blending of dyed tops:

Florence Dye Works
Woonsocket, Rhode Island

3) Spinning of yarns from dyed and blended tops:

Westbrook Spinning Company
Westbrook, Maine

4) Weaving:

Textile Research Services
Raleigh, North Carolina

5) Finishing of fabrics:

Florence Finishing Company
Woonsocket, Rhode Island

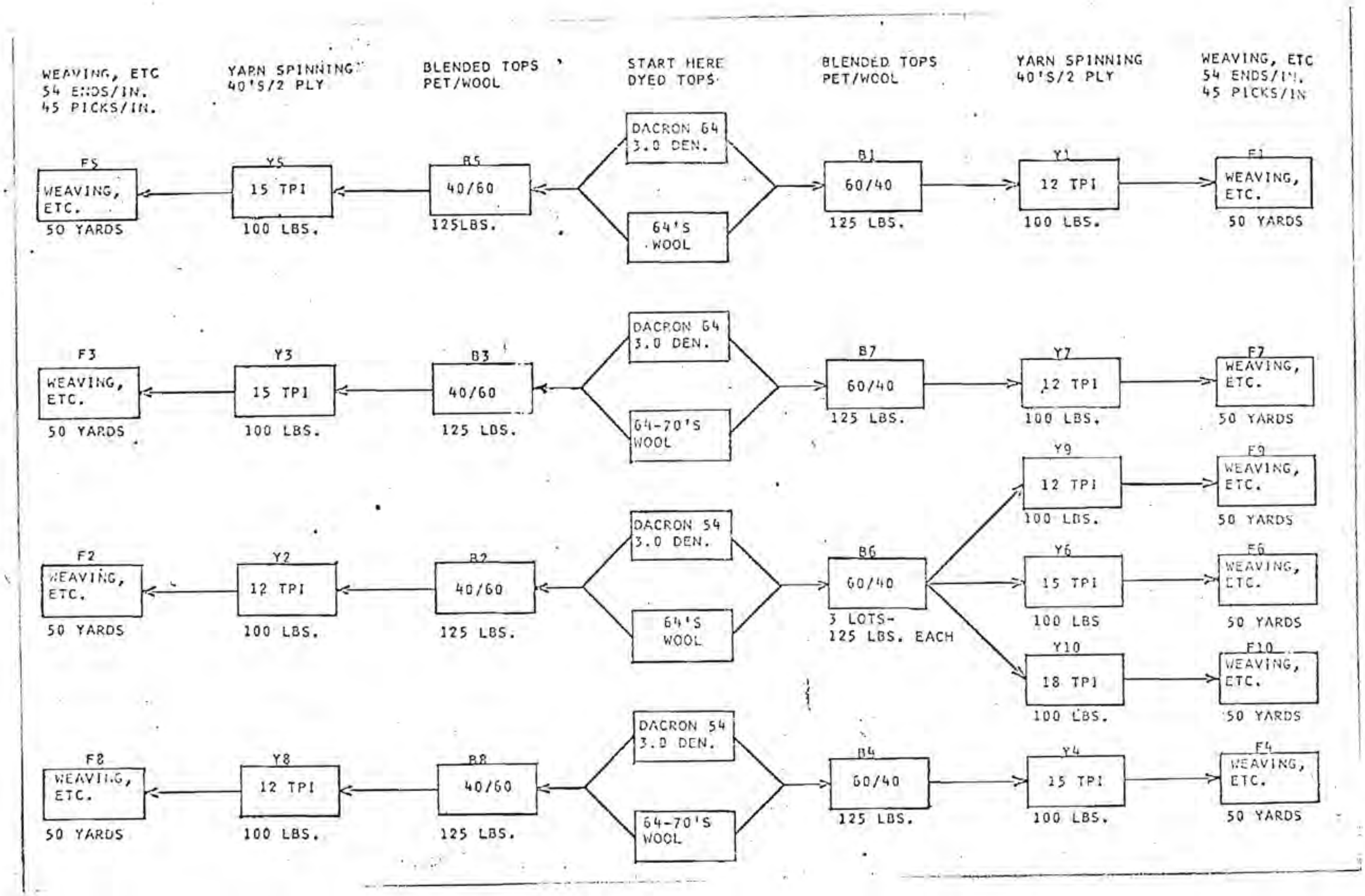

WEAVING, ETC
54 ENDS/IN.
45 PICKS/IN.
YARN SPINNING
40'S/2 PLY
BLENDED TOPS
PET/WOOL
START HERE
DYED TOPS
BLENDED TOPS
PET/WOOL
YARN SPINNING
40'S/2 PLY
WEAVING, ETC
54 ENDS/IN.
45 PICKS/IN
DACRON 64
3.0 DEN.
64'S
WOOL
F5
WEAVING, ETC.
50 YARDS
Y5
15 TPI
100 LBS.
B5
40/60
125LBS.
B1
60/40
125 LBS.
Y1
12 TPI
100 LBS.
F1
WEAVING, ETC.
50 YARDS
DACRON 64
3.0 DEN.
64-70'S
WOOL
F3
WEAVING, ETC.
50 YARDS
Y3
15 TPI
100 LBS.
B3
40/60
125 LBS.
B7
60/40
125 LBS.
Y7
12 TPI
100 LBS.
F7
WEAVING, ETC.
50 YARDS
Y9
12 TPI
100 LBS.
F9
WEAVING, ETC.
50 YARDS
DACRON 54
3.0 DEN.
64'S
WOOL
F2
WEAVING, ETC.
50 YARDS
Y2
12 TPI
100 LBS.
B2
40/60
125 LBS.
B6
60/40
3 LOTS-
125 LBS. EACH
Y6
15 TPI
100 LBS
F6
WEAVING, ETC.
50 YARDS
Y10
18 TPI
100 LBS.
F10
WEAVING, ETC.
50 YARDS
DACRON 54
3.0 DEN.
64-70'S
WOOL
F8
WEAVING, ETC.
50 YARDS
Y8
12 TPI
100 LBS.
B8
40/60
125 LBS.
B4
60/40
125 LBS.
Y4
15 TPI
100 LBS.
F4
WEAVING, ETC.
50 YARDS

FIGURE 5

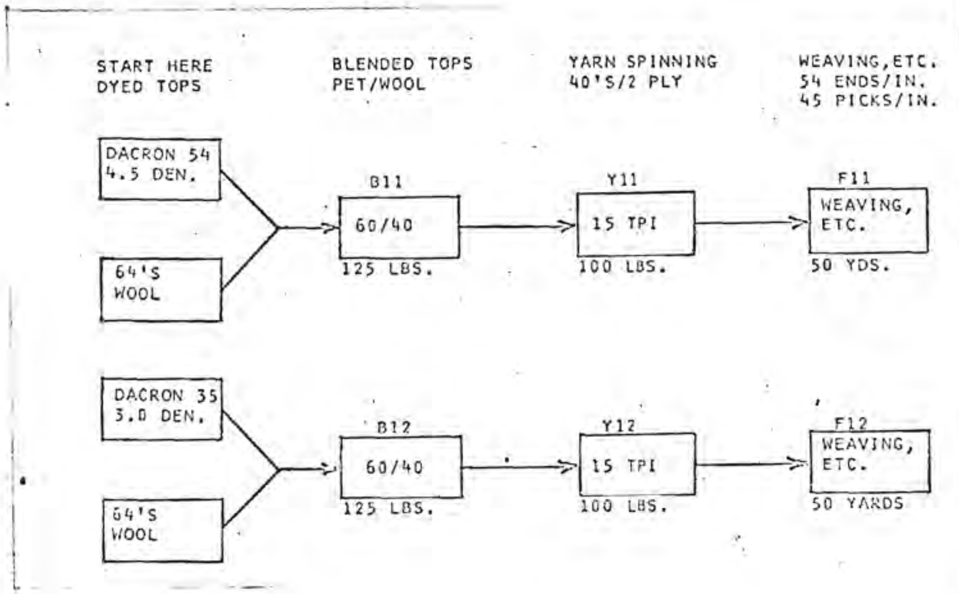

START HERE
DYED TOPS
BLENDED TOPS
PET/WOOL
YARN SPINNING
40'S/2 PLY
WEAVING,ETC.
54 ENDS/IN.
45 PICKS/IN.
DACRON 54
4.5 DEN.
64'S
WOOL
B11
60/40
125 LBS.
Y11
15 TPI
100 LBS.
F11
WEAVING,
ETC.
50 YDS.
DACRON 35
3.0 DEN.
64'S
WOOL
B12
60/40
125 LBS.
Y12
15 TPI
100 LBS.
F12
WEAVING,
ETC.
50 YARDS

FIGURE 6

Fabrics

F1

F2

F3

F4

F5

F6

F7

F8

F9

F10

F11

F12

Carbonized

Finishing will be same for all fabrics after fabrics F1,F2 F3, and F4 have been carbonized, i.e., standard finishing for tropical worsted uniform fabrics.

FIGURE 7

At the completion of each stage in the manufacture of these fabrics, the company providing services will submit detailed processing information and appropriate samples for evaluation at Georgia Tech.

B. Status of Experimental Fabric Program

A schedule describing the expected progress in the experimental fabric program has been previously submitted. This schedule was as follows:

Services	Company	Date of Shipping
Supplier of fiber top	Wellman, Inc.	5 April 1973
Dyeing and blending	Florence Dye Works	7 May 1973
Spinning of yarn	Westbrook Spinning Co.	29 June 1973
Weaving	Textile Research Services	29 July 1973
Fabric Finishing	Florence Finishing Co.	15 August 1973

The current schedule is as follows:

Services	Company	Date
Supplier of fiber tops	Wellman, Inc.	Shipped approximate 10 April 1973
Dyeing and blending	Florence Dye Works	Received top 19 April 1973 Will ship 15 June 1973
Spinning of yarn	Westbrook Spinning Co.	Will receive 15 June 1973 Will ship first lot 1 July 1973 Will ship last lot 20 July 1973
Weaving of fabric	Textile Research Services	Will receive first lot 1 July 1973 Will ship all fabrics 7 August 1973
Finishing of Fabrics	Florence Finishing Co.	Will receive fabrics 7 August 1973 Will ship fabrics 22 Aug. 1973

Although this schedule is different from the one previously given, it is expected that the fabrics should be received at Georgia Tech on approximately 22 August 1973 which is only one week later than the previous schedule. Except for the detailed analysis of the finished fabrics most of the analyses of the materials at intermediate steps in the manufacturing process will have been completed before the fabrics are received.

As of the writing of this report, all dyeings have been completed and the blending of the dyed tops is proceeding as scheduled to meet the shipping date of 15 June for the dyed and blended top to the Westbrook Spinning Company.

V. Overall Program Status

The Phase III of the Air Force Project, Contract No. F33615-72-C-1822 specifies that the contractor will prepare wool/polyester fabrics (head-end pieces) in which the wool grade, polyester fiber, yarn ply, and other processing conditions have been varied to achieve the objectives of fabrics ranging from the best that can be achieved at costs comparable to that for present materials (or a minimum increase in cost), to the best possible improvement at a modest increase in cost. Following an evaluation of these fabrics, the contractor is required to produce six (6) 500 yd. pieces of fabric, the choice of fabrics to be mutually selected by the contractor and AFML technical monitor.

The progress made on this program to date is in accord with the program schedule outlined by AFML and agreed to by the contractor with the exception of the time delay in the production of experimental fabrics. This time delay is due to extreme difficulties encountered in securing the outside services required. The search for outside sources was begun in August, 1972. No fully integrated major manufacturers of worsted fabrics would undertake such a small-scale development program at a time when many worsted manufacturers, large and small, were getting out of the worsted business. After contacting approximately fifteen firms, the contractor secured the services of five firms required to produce the experimental fabrics as described in this report. The production of these fabrics is now in progress; however, it is estimated that this phase of the program is approximately three (3) months behind schedule. Therefore, it is anticipated that there will be a time delay of approximately three (3) months to complete this program. A formal request for an extension of the contract will be made at a later date. It is understood that any requested extension of the contract is at no increased cost to the government.

E-27-613

Interim Technical Report Number 3

(15 May 1973 to 15 November 1973)

Exploratory Development on Polyester/Wool

Uniform Fabric with Improved Durability and Appearance

Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

(Prepared under Contract No. F33615-72-C-1822

by Georgia Institute of Technology, Atlanta, Georgia,

W. C. Carter, author)

Abstract

This report includes the status of the evaluation of samples generated in the experimental fabric program designed to determine the contribution of variables in the composition, structure, and processing conditions on abrasion properties. All fabrics required in this program have now been made, the only remaining step in processing being fabric finishing which should be completed by 15 December, 1973.

Detailed analyses of wool and polyester tops, blended polyester/wool tops, yarns, and fabric have been made as well as preliminary abrasion tests. The results of these analyses indicates that considerable care was exercised by subcontractors to meet the requirements of the program. Preliminary abrasion tests show conclusively that it will be possible to sort out the effects of variables being studied which affect abrasion behavior. The abrasion studies on the woven fabrics will begin as soon as fabric finishing has been completed (15 December, 1973).

TABLE OF CONTENTS

I. Introduction

Previous Interim Reports 1 and 2, for the periods 15 May 1972 to 15 November 1972 and 15 November 1972 to 15 May 1973, respectively, described exploratory work which was done to establish those variables in the composition and structure of polyester/wool uniform fabrics as well as the variables in the production of these fabrics which affect abrasion resistance. These studies included:

1) the determination of the nature of the frosting of uniform fabrics;
2) an evaluation of the abrasion resistance of commercially available polyester fibers and the relationship of their abrasion resistance and stress-strain behavior;
3) the determination of the variables in the dyeing process used for polyester fibers on their abrasion resistance;
4) selection of dyes and dyeing conditions for polyester and wool fibers.

These studies have served as a basis for the design of an experiment to sort out the relative contributions of variables in the production of polyester/wool uniform fabrics to abrasion. This design was described in the Interim Report No. 2, and is shown in flow charts, Figures 1, 2, and 3. This report includes the evaluation of fiber tops, yarns, and fabrics generated in this program.

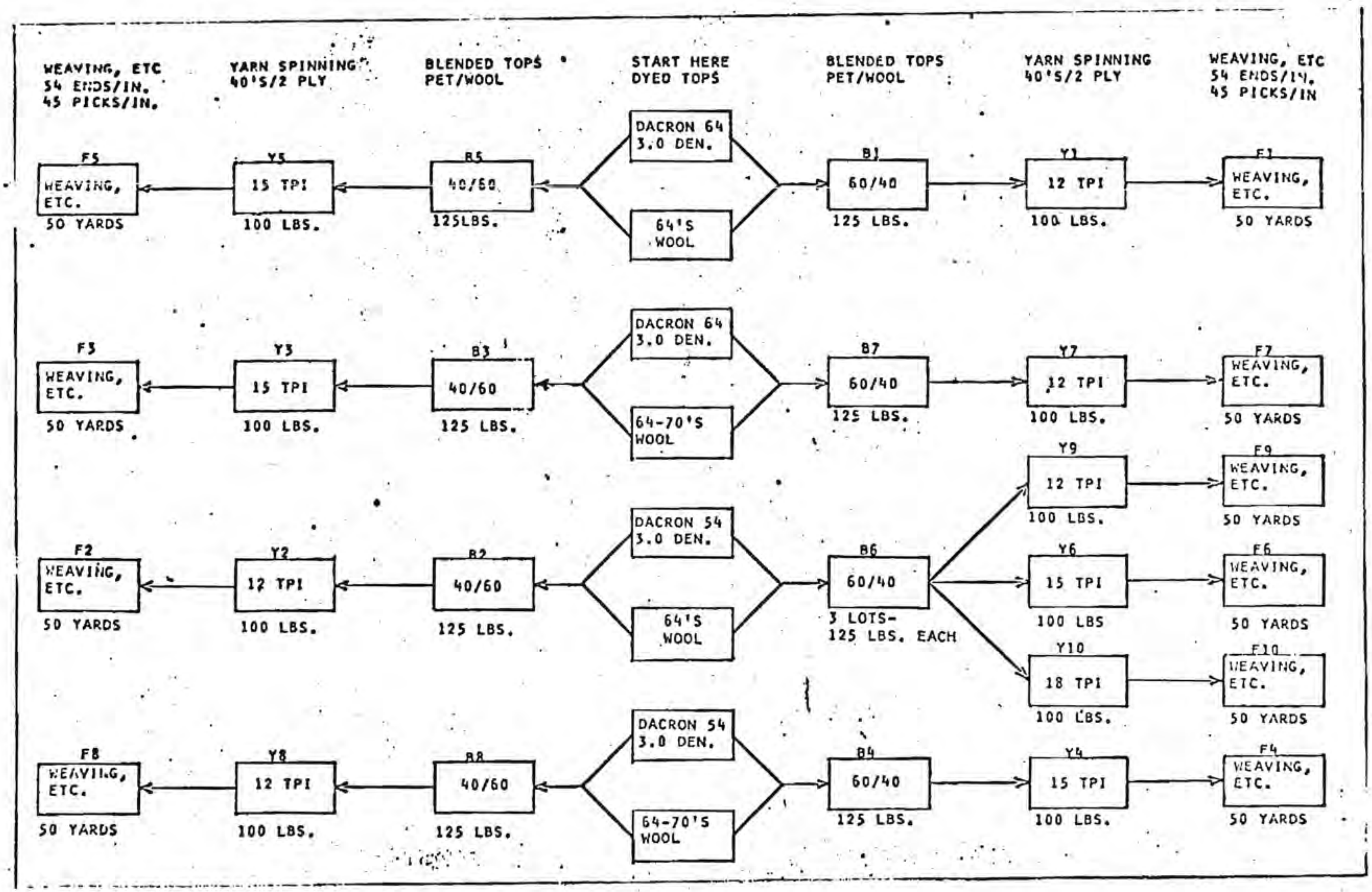

WEAVING, ETC
54 ENDS/IN.
45 PICKS/IN.
YARN SPINNING
40'S/2 PLY
BLENDED TOPS
PET/WOOL
START HERE
DYED TOPS
BLENDED TOPS
PET/WOOL
YARN SPINNING
40'S/2 PLY
WEAVING, ETC
54 ENDS/IN.
45 PICKS/IN
F5
WEAVING, ETC.
50 YARDS
Y5
15 TPI
100 LBS.
B5
40/60
125LBS.
DACRON 64
3.0 DEN.
64'S
WOOL
B1
60/40
125 LBS.
Y1
12 TPI
100 LBS.
F1
WEAVING, ETC.
50 YARDS
F3
WEAVING, ETC.
50 YARDS
Y3
15 TPI
100 LBS.
B3
40/60
125 LBS.
DACRON 64
3.0 DEN.
64-70'S
WOOL
B7
60/40
125 LBS.
Y7
12 TPI
100 LBS.
F7
WEAVING, ETC.
50 YARDS
Y9
12 TPI
100 LBS.
F9
WEAVING, ETC.
50 YARDS
F2
WEAVING, ETC.
50 YARDS
Y2
12 TPI
100 LBS.
B2
40/60
125 LBS.
DACRON 54
3.0 DEN.
64'S
WOOL
B6
60/40
3 LOTS-
125 LBS. EACH
Y6
15 TPI
100 LBS
F6
WEAVING, ETC.
50 YARDS
Y10
18 TPI
100 LBS.
F10
WEAVING, ETC.
50 YARDS
F8
WEAVING, ETC.
50 YARDS
Y8
12 TPI
100 LBS.
B8
40/60
125 LBS.
DACRON 54
3.0 DEN.
64-70'S
WOOL
B4
60/40
125 LBS.
Y4
15 TPI
100 LBS.
F4
WEAVING, ETC.
50 YARDS

FIGURE 1

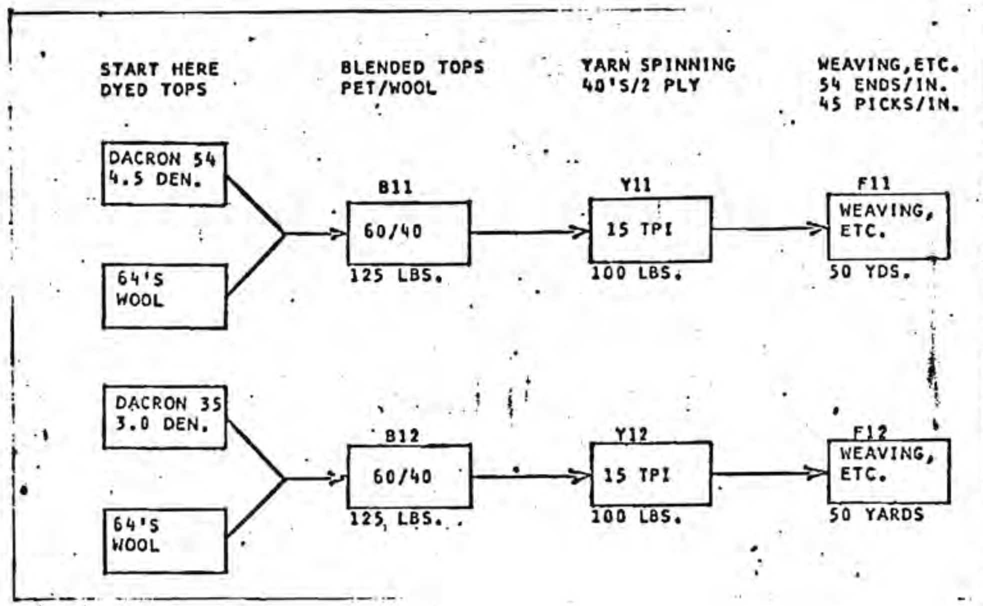

START HERE
DYED TOPS
BLENDED TOPS
PET/WOOL
YARN SPINNING
40'S/2 PLY
WEAVING,ETC.
54 ENDS/IN.
45 PICKS/IN.
DACRON 54
4.5 DEN.
64'S
WOOL
B11
60/40
125 LBS.
Y11
15 TPI
100 LBS.
F11
WEAVING,
ETC.
50 YDS.
DACRON 35
3.0 DEN.
64'S
WOOL
B12
60/40
125 LBS.
Y12
15 TPI
100 LBS.
F12
WEAVING,
ETC.
50 YARDS

FIGURE 2

Fabrics

F1

F2

F3

F4

F5

F6

F7

F8

F9

F10

F11

F12

→ Carbonized

→ Finishing will be same for all fabrics after fabrics F1, F2, F3, and F4 have been carbonized, i.e., standard finishing for tropical worsted uniform fabrics.

FIGURE 3

II. Experimental Fabric Program

A. Status

The production of the experimental fabrics is now in its last phase, namely fabric finishing. The fabrics woven by Fabric Research Services were shipped November 29, 1973, to Florence Finishing Company for finishing. It is anticipated that the finishing will be completed by December 15. As previously reported, numerous delays have occurred in each phase of this program necessitating a request for extension of the completion date for the contract. As each phase in the program was completed, samples were obtained for evaluation. The experimental work done on these samples is described in this report.

B. Analysis of Samples Generated in Fabric Program

1. Undyed Wool and Polyester Tops

The polyester and wool tops in this program were supplied by Wellman, Inc. They converted polyester tow to top, the cut fiber length being nominally 3.5 inches. Uster evenness tests were made on the tops and all of them were found to be quite uniform. Fiber diagrams were also made and the mean fiber lengths are shown in Table I. The distribution in fiber lengths was found to be very narrow for the polyester samples, and, as predicted, quite broad for the wool samples. The average weights of the tops are shown in Table II. Again, all of the undyed tops have approximately the same linear density.

2. Dyed Tops and Blended Dyed Tops

The dyeing, blending, and combing of the polyester and wool tops was done by Florence Dye Works. Prior to dyeing, the supplied tops were converted to tops having different weights per yard as required for the

TABLE I

UNDYED STAPLE LENGTH

Fiber	Mean Staple Length (in.)
Dacron 35 (3.0 denier)	3.67
Dacron 54 (3.0 denier)	3.76
Dacron 64 (3.0 denier)	--*
Dacron 54 (4.5 denier)	3.74
Wool 64's	2.88
Wool 64's-70's	3.09

*not available

TABLE II

WEIGHTS OF UNDYED TOPS

Weight of Tops (Undyed)	grains/yd.
Dacron 35 (3.0 denier)	271
Dacron 54 (3.0 denier)	270
Dacron 54 (4.5 denier)	280
Dacron 64 (3.0 denier)	---*
Wool 64's	287
Wool 64's-70's	277

*not available

dyeing operation. The dyed tops used in the preparation of the blended tops were analyzed as follows:

a) linear density (grains/yd.),

b) color,

c) denier per filament, and

d) breaking stress and breaking elongation.

The weights (linear density) of the dyed tops are shown in Table III. The color measurements for the dyed tops are shown in Table IV. The color measurements were made on hand-carded samples behind glass and therefore should not be compared with measurements made on fabrics which are normally not made behind glass. Inspection of these data indicate that all of the tops have approximately the same color with the exception of the Dacron 54 (4.5 denier) sample which is somewhat darker in shade than the others. The chromaticity coordinates x and y define a dominant wavelength of approximately 468 nm compared with the value of 466 nm for the Air Force Standard.

The single filament deniers, breaking stress (g/den) and breaking elongation (%) values for the dyed samples are shown in Table V. The values given are the average for forty (40) specimens. The stress-strain curves will be analyzed further to establish the initial moduli and energies to rupture. This information will be used to assess the relationship between stress-strain properties and abrasion resistance of the experimental fabrics.

3. Blended Tops (Dyed)

The dyed polyester and wool tops were blended and combed according to flow charts, Figures 1 and 2. The linear densities of the blended tops

TABLE III

DYED TOPS - LINEAR DENSITY

Weight of Dyed Top Used in Making Blended Tops (grains/yd.)	
Dacron 45 (3.0 denier)	169
Dacron 54 (3.0 denier)	128
Dacron 54 (4.5 denier)	180
Dacron 64 (3.0 denier)	143
Wool (64's)	168
Wool (64's-70's)	207

TABLE IV

COLOR OF DYED TOPS USED TO PREPARE BLENDED TOPS

	C.I.E. Tristimulus Values			Chromaticity Coordinates	
Fiber	X	Y	Z	X	Y
Dacron 35 (3.0 denier)	0.1078	0.1072	0.1525	0.2934	0.2918
Dacron 54 (3.0 denier)	0.1099	0.1096	0.1588	0.2906	0.2896
Dacron 54 (4.5 denier)	0.1026	0.1025	0.1457	0.2926	0.2921
Dacron 64 (3.0 denier)	0.1070	0.1071	0.1500	0.2938	0.2942
Wool 64's	0.1091	0.1084	0.1552	0.2927	0.2909
Wool 64's-70's	0.1093	0.1085	0.1546	0.2935	0.2915

TABLE V

SINGLE FILAMENT PROPERTIES OF DYED FIBERS

	Denier	C.V. %	Breaking Strength g/den	C.V. %	Breaking Strength g/den	C.V. %
Dacron 35 (3.0 denier)	3.22	11	3.31	10	25.1	29
Dacron 54 (3.0 denier)	3.00	12	4.35	14	28.1	37
Dacron 54 (4.5 denier)	4.93	12	4.20	14	36.0	28
Dacron 64 (3.0 denier)	3.30	10	3.10	9	21.9	29
Wool (64's)	5.43	29	1.15	28	18.7	53
Wool (64's-70's)	5.64	25	0.93	20	15.4	71

TABLE VI

DYED AND BLENDED TOPS

Blend No.*	Weight of Dyed and Blended Top Supplier to Spinner (grains/yd.)
B1	226
B2	235
B3	230
B4	243
B5	239
B6	234
B7	252
B8	245
B11	241
B12	231

*See Figures 1, 2.

supplied to the spinner, Westbrook Spinning Company, are shown in Table VI. Color measurement were made on hand-carded blended tops behind glass and are recorded in Table VII. As would be predicted from the color measurements on the unblended tops, the tristimulus values and chromaticity coordinates are essentially the same for all samples.

4. Analysis of Yarns

a. Composition of Experimental Yarns

Duplicate analysis of the twelve experimental yarns for extractables and fiber content have been made. The results of these analyses are shown in Table VIII.

It is concluded that the blending of the dyed tops was accomplished as required in the program.

b. Yarn Count and Twist

Yarns prepared by Westbrook Spinning have been analyzed for size (count) and twist levels. The count for the Air Force Tropical worsted fabrics is 40's two-ply (worsted system) corresponding to an equivalent singles worsted count of approximately 20's. The yarn twist is 12 turns per inch in the singles and 12 turns per inch in the ply to produce a balanced twist. These specifications were arrived at previously from an analysis of the standard Air Force uniform fabric. Federal Test Methods corresponding to ASTM Test Methods were used to obtain the count and twist data in Table IX.

5. Analysis of Knit Fabrics Prepared from Experimental Yarns

In order to obtain some abrasion results before the production of the woven fabrics has been completed, the experimental yarns were knitted in the form of a sleeve on the Lawson Hemphill Knitting Analyzer. These knitted samples have been used for color measurements and abrasion studies.

TABLE VII

COLOR OF BLENDED AND DYED TOPS USED TO PREPARE YARNS

Blend No.*	C.I.E. Tristimulus Values X	Y	Z	Chromaticity Coordinates X	Y
B1	0.1070	0.1072	0.1480	0.2955	0.2958
B2	0.1073	0.1083	0.1493	0.2941	0.2967
B3	0.1051	0.1052	0.1467	0.2961	0.2964
B4	0.1046	0.1042	0.1461	0.2931	0.2936
B5	0.1069	0.1063	0.1491	0.2951	0.2933
B6	0.1067	0.1058	0.1492	0.2950	0.2925
B7	0.1044	0.1040	0.1449	0.2955	0.2944
B8	0.1061	0.1056	0.1483	0.2947	0.2932
B11	0.1023	0.1020	0.1442	0.2936	0.2926
B12	0.1044	0.1044	0.1437	0.2961	0.2961

*See Flow Charts, Figures 1 and 2.

TABLE VIII

FIBER CONTENT OF POLYESTER/WOOL YARNS

Yarn Designation	Polyester Component	Wool Component	Target Composition Polyester/Wool	Composition Found Polyester/Wool*
Y1	Dacron 64 3.0 den	64's	60/40	60.8/39.2
Y2	Dacron 54 3.0 den	64's	40/60	41.5/58.5
Y3	Dacron 64 3.0 den	64-70's	40/60	40.2/59.8
Y4	Dacron 54 3.0 den	64-70's	60/40	61.3/38.7
Y5	Dacron 64 3.0 den	64's	40/60	40.6/59.4
Y6	Dacron 54 3.0 den	64's	60/40	62.4/37.6
Y7	Dacron 64 3.0 den	64-70's	60/40	60.4/39.6
Y8	Dacron 54 3.0 den	64-70's	40/60	40.5/59.5
Y9	Dacron 54 3.0 den	64's	60/40	62.0/38.0
Y10	Dacron 54 3.0 den	64's	60/40	61.8/38.2
Y11	Dacron 54 4.5 den	64's	60/40	62.4/37.6
Y12	Dacron 35 3.0 den	64's	60/40	59.7/40.3

*These analyses are based on the oven-dry weight of the chloroform extracted yarns.

TABLE IX

WORSTED COUNT AND TWIST OF POLYESTER/WOOL YARNS

Designation	Worsted Count* (Equivalent Singles)	Yarn Twist (tpi) Target (Singles and Ply)	Found Singles	Found Ply
Y1	18.9	12	11.4	13.0
Y2	19.7	12	11.0	13.2
Y3	19.6	15	13.8	15.8
Y4	19.5	15	13.8	15.4
Y5	15.7**	15	13.7	16.0
Y6	19.8	15	14.1	15.9
Y7	19.3	12	11.5	12.8
Y8	20.6	12	11.2	13.4
Y9	18.7	12	11.5	13.2
Y10	20.1	18	16.7	19.9
Y11	20.1	15	13.8	15.6
Y12	20.1	15	13.9	15.7

*target 20's worsted system

**Y5 - this low value is due to a mistake made by Westbrook, 32's singles were made whereas their instructions were to prepare 40's singles. Thus, the fabric made from the yarn will be approximately twenty percent heavier than specified and its abrasion properties will be a function of the larger yarn size; however, in the statistical analysis of the abrasion properties of the fabrics, the effect of having the wrong yarn size (Y5) will be one of decreasing the variance due to main effects and increasing the variance attributed to error.

a. Color Measurements

The tristimulus values for the knitted fabrics are shown in Table X. In order to assess the variability in shade amongst the samples, color differences calculations have been made using the average of the tristimulus values for all twelve samples as a reference. The color differences are expressed in NBS units, a color difference of less than one (1.0) being defined a commercially acceptable color match. With the exception of sample F11 (refer to Figures 1 and 2), color differences of less than 1.0 were found. Sample F11 contains Dacron 54, 4.5 denier, and the value of 1.36 NBS units for this sample is attributed to the greater denier of the fiber in this sample. It should be noted that all of the samples are significantly different from the Air Force Standard; however the difference is not one of a hue difference but rather a lightness difference, the Air Force Standard being lighter in depth. This means that by making very simple corrections to the dyeing formulation (a reduction in total color used), it will be possible to match the Air Force Standard.

b. Abrasion of Knitted Fabrics

The knitted fabrics described above have been abraded using the flat-abrasion test as described in the Technical Manual of the American Association of Textile Chemists and Colorists, Test Method 119-1970. This test calls for the Stoll Universal Wear Tester Model CS-22C with a frosting attachment. The abrading surface is a stainless steel wire screen. Each sample was abraded for 10,000 and 12,000 cycles and examined after each 1,000 cycles. There are two features of the abraded surfaces, namely, pilling and frosting. In these specimens, pilling seems to predominate, probably because of the fact that the yarns are in a knit structure and movement of yarns during abrasion will be greater in such a structure as opposed to their movement

TABLE X

COLOR MEASUREMENTS ON KNIT FABRICS PREPARED FROM BLEND YARNS

Fabric	Tristimulus Values X	Y	Z	Color Difference Between Fabric and Reference* (NBS Units)**
Reference*	.0354	.0336	.0642	----
F1	.0342	.0328	.0625	0.67
F2	.0357	.0338	.0649	0.23
F3	.0341	.0325	.0603	0.90
F4	.0361	.0343	.0659	0.30
F5	.0339	.0325	.0612	0.79
F6	.0345	.0325	.0627	0.52
F7	.0348	.0330	.0638	0.33
F8	.0366	.0348	.0662	0.41
F9	.0360	.0341	.0666	0.61
F10	.0363	.0344	.0680	0.92
F11	.0360	.0339	.0683	1.36
F12	.0367	.0350	.0679	0.69
Air Force Tropical Standard	.0486	.0454	.0883	4.01

*Reference is a hypothetical fabric whose tristimulus values are the average of the tristimulus values for all twelve (12) experimental fabrics.

**1 NBS unit difference is defined as the limit for a commercially acceptable color match.

in a tightly woven structure. In spite of this drawback in the experiment, certain conclusions have been reached from examination of the abraded fabrics. These conclusions are presented below as they relate to the variables included in making the experimental fabrics.

1) Effect of Grade of Wool

This effect is very small but it appears that the abrasion resistance is poorer for those fabrics containing 64's-70's wool.

2) Effect of Fiber Content

Fabrics having a composition 60% wool/40% polyester show less change in appearance on abrasion than those having a composition 40% wool/60% polyester.

3) Effect of Type of Polyester

Fabrics containing Dacron 54 pill much worse than those containing Dacron 64; however, there is evidence that frosting occurs more on fabrics containing Dacron 64. Dacron 35 appears to be better than either Dacron 54 or Dacron 64.

4) Effect of Yarn Twist

A decrease in the tendency to pill results from an increase in the yarn twist.

The results of this work on knitted fabrics show clearly that it will be possible to sort out the effects of variables in the production of polyester/wool uniform fabrics on fabric abrasion. The work on the finished experimental woven fabrics should commence December 15.

6. Analysis of Head-End Piece of Experimental Woven Fabric

The weights of the experimental fabric in their loom state and the number of yarns per inch in both warp and filling directions have been determined. The results are shown in Table XI. With the exception of fabric F5, the fabric weights are close to the target of 5.79 oz./yds. The higher weight for F5 is due to a mistake made in yarn spinning (see Table IX). The measured ends and picks per inch are also close to the target values. With the exception of sample F5, it will be possible to meet all fabric specifications after fabric finishing.

TABLE XI

ANALYSIS OF FABRICS (HEAD-END PIECES) (NOT FINISHED)

Fabric	Average No. of Yarns/in. Warp	Filling	Fabric Weight (oz./yd^2)
F1	54.4	42.6	5.88
F2	53.4	42.6	5.50
F3	54.2	44.4	5.63
F4	52.0	44.3	5.49
F5	54.4	43.0	7.215
F6	52.8	43.8	5.47
F7	54.6	43.8	5.63
F8	53.4	43.0	5.20
F9	54.0	43.6	5.67
F10	54.0	42.8	5.57
F11	54.2	42.8	5.45
F12	54.0	44.6	5.63
Air Force Tropical Standard	54*	45*	5.79*

*Finished fabric.

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Interim Technical Report No. 4

(15 November, 1973 to 15 May, 1974)

Exploratory Development of Polyester/Wool Uniform
Fabric with Improved Durability and Appearance

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Abstract

This Interim Report includes the complete evaluation of experimental polyester/wool worsted fabrics produced as a part of a program to develop polyester/wool uniform fabrics with improved durability and appearance. The experimental results described were presented at a technical conference held at the Georgia Institute of Technology, 30 April, 1974. The purpose of this conference was to provide an industry assessment of the adaptability of newly developed fabrics to current production methods, including all aspects of production from the choice of raw materials, yarn and fabric construction, dyeing and finishing processes, to uniform fabrication. Based on the results of the work presented at the technical conference as described in this report and its critique by experts in the manufacture and utilization of polyester/wool worsted fabrics, recommendations are made with respect to production-run fabrics which will be made to complete the last phase of this program. These recommendations are included in this report.

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I. Introduction

As a part of this program to develop polyester/wool uniform fabrics with improved durability and appearence, the production of experimental fabrics was required in order to determine the effects of variables in the composition and structure of the fabrics on fabric properties, particularly their abrasion resistance. These fabrics have been prepared and evaluated. In order to have input for this program from various segments of industry concerned with uniform fabrics, a technical conference was held at Georgia Tech on April 30, 1974 at which time the results of work done at Georgia Tech were presented.

Those people attending the conference included representatives of polyester fiber producer interests, wool interests, textile producer interests, and representatives of ASD/ENCO and Natick Laboratory who have considerable expertise in the fabrication and performance of military uniforms. Following the presentation of the results obtained in the experimental fabric program, recommendations with respect to the composition and construction of the production run fabrics were made. The attendees provided an excellent critique of both the work which was presented and the recommended production run fabrics. Industry assessment of the adaptability of newly developed fabrics to current production methods was also sought, including all aspects of production from the choice of raw materials, yarn and fabric construction, dyeing and finishing processes, to the fabrication of uniforms.

This report includes a description of the experimental fabric program, the complete evaluation of the experimental fabrics, and recommendations with respect to production-run fabrics.

A report on the Technical Conference held at Georgia Tech is appended.

II. Description of Experimental Fabric Program

The design of an experimental program to sort out the effect of variables in the composition, construction, and processing of polyester/wool uniform fabrics on fabric properties, particularly abrasion resistance, was based on information obtained from several sources:

1. Discussions with fiber and textile manufacturers as well as manufacturers of dyes and dyeing assistants
2. Technical information available from fiber manufacturers
3. Literature in technical journals related to fiber and fabric abrasion (pilling and frosting) and
4. Work previously done in this program.

It was concluded that the variables which should be investigated in a statistically designed experiment were as follows:

1. Polyester type
2. Grade of wool
3. Relative amounts of wool and polyester in blend
4. Yarn twist
5. Carbonizing
6. Combings (number of)
7. Denier of polyester fiber

To minimize the number of fabrics required for this experiment, it was decided that the basic design would be a 2^5 design, the five variables being the first five listed above at two levels for each variable. A fractional factorial experiment (5 factors in 8 observations) was performed, i.e. eight (8) fabrics. The production of four additional fabrics made possible an evaluation of an additional level for variable 1 (polyester type) and variable 4 (yarn twist) as well as an evaluation of the effect of the denier of the polyester fiber on abrasion.

The variable and levels for each variable arranged in decreasing order of their estimated importance in abrasion were as follows:

Variable	Level −	Level +
A. Polyester Type (3 denier)	Dacron 64	Dacron 54
B. Grade of Wool (Domestic)	64's	64-70's
C. Carbonizing	yes	no
D. Composition of Blend-Polyester/Wool	60/40	40/60
E. Yarn Twist (t.p.i.)	12	15

The experiments performed are described below:

Fractional Factorial for 2^5 Design (1/4 replicate)

Equate D to ABC
E to -BC

	A	B	C	D	E	Treat. Comb.	Effects and Aliases
Y_1	−	−	−	−	−	1	A, -DE
Y_2	+	−	−	+	−	ad	B, -CE
Y_3	−	+	−	+	+	bde	C, -BE
Y_4	+	+	−	−	+	abe	D, -AE
Y_5	−	−	+	+	+	cde	E, -BC, -AD
Y_6	+	−	+	−	+	ace	AB, CD
Y_7	−	+	+	−	−	bc	AC, BD
Y_8	+	+	+	+	−	abcd	

$D(D=ABC) = (D^2=ABCD) = (I=ABCD)$

$E(E=BC) = (E^2=-BCE) = (I=-BCE)$

$(ABCD)(-BCE) = -ADE$

defining contrasts I, ABCD, -BCE, -ADE

aliases - (i) A, BCD, -ACE, -DE
(ii) B, ACD, -CE, -ABDE
(iii) C, ABD, -BE, -ACDE
(iv) D, ABC, -BCDE, -AF
(v) E, ABCDE, -BC, -AD
(vi) AB, CD, -ACE, -BDE
(vii) AC, BD, -ABE, -CDE

Notes:

1. In order to obtain additional information concerning the effect of yarn twist, the composition corresponding to Y_6 in the design was converted to two additional fabrics in which the yarn twist was 12 tpi and 18 tpi. The fabrics produced from these yarns were designated Y_9 and Y_{10} respectively.
2. In order to determine the effect of polyester denier, another fabric was prepared in which a 4.5 denier Dacron 54 replaced the 3.0 denier Dacron 54 in the sample described as Y_6. This fabric was designated Y_{11}.
3. It was desirable to evaluate another polyester fiber, whose properties differ from those of Dacron 54 and Dacron 64. To accomplish this, a fabric sample was prepared in which 3.0 denier Dacron 35 replaced the 3.0 denier Dacron 54 in the sample described as Y_6. This fabric was designated Y_{12}.

In summary, ten different blended polyester/wool tops were prepared from which twelve sample fabrics were made.

A complete description of the fabrics produced is shown in Table I. Approximately fifty (50) yards of each fabric were prepared, one-half of which was singed in finishing. The remaining one-half was not singed.

The companies who supplied the necessary services for producing the experimental fabrics are as follows:

1. Source of Wool tops and polyester tops:

   Wellman, Incorporated
   Johnsonville, South Carolina

2. Dyeing and blending of dyed tops:

   Florence Dye Works
   Woonsocket, Rhode Island

3. Spinning of yarns from dyed and blended tops:

   Westbrook Spinning Company
   Westbrook, Maine

FABRIC DESIGNATION

YARN TWIST (t.p.i.)
SINGLES AND PLY

CARBONIZED

TABLE I

Test Method:

Polyester	Wool	40/60 Polyester/Wool Sample No.	40/60 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results
Dacron Type 64 3.0 d.p.f.	64s	5-15		1-12C			
	64s-70s	3-15C		7-12			
Dacron Type 54 3.0 d.p.f.						9-12	
	64s	2-12C		6-15			
						10-18	
	64s-70s	8-12		4-15C			
Dacron Type 54, 4.5 d.p.f./64s wool				11-15			
Dacron Type 35, 3.0 d.p.f./64s wool				12-15			
Air Force Tropical Standard No. 1							
Air Force Tropical Standard No. 2							
Air Force Gabardine Standard							
Air Force Serge Standard							

4. Weaving of fabrics:

   Textile Research Services
   Raleigh, North Carolina

5. Finishing of Fabrics

   Florence Finishing Company
   Woonsocket, Rhode Island

The processing conditions used in the preparation of these fabrics as well as the yarn and fabric construction have been judged to be the same as those described in the Military Specifications, MIL - C - 21115 G. In these specifications, details of fabric construction are given but there is no specification of yarn twist. In this program, yarn twists of 12,15, and 18 t.p.i. were used whereas, the Air Force Tropical Standard fabric was shown to have a twist of 10-11 t.p.i. in both the singles and plied yarn. The Military Specifications call for the use of a 3.0 denier per filament polyester fiber, the composition of which must be essentially poly (ethyleneterephthalate). This allows the textile manufacturer to use a variety of polyester fibers differing in molecular weight of the polymer from which they are produced, differing in degrees of molecular order, and differing in chemical composition, e.g. cationic dyeable polyester fibers. From an examination of three different Air Force standard fabrics, it was discovered that the polyester fibers used did indeed differ in their chemical composition, i.e. both cationic and non-cationic dyeable polyester fibers were used in their production.

With the exception of the weaving of the experimental fabrics, all processing was carried out on commercial size equipment by industrial firms familiar with and actively engaged in the production of 100 per cent wool and polyester/wool worsted fabrics.

III. Experimental Methods Used in the Evaluation of Experimental Fabrics.

The test methods used in the evalution of the experimental fabrics included those methods which are required in Military Specifications for the Type III, Class 1 polyester/wool tropical worsted fabrics as defined in MIL-C-21115G. These methods are those described in Federal Test Method Standards 191, "American Society for Testing and Materials Standards" (ASTM) and the "Technical Manual of the American Association of Textile Chemists and Colorists". A list of the methods used is shown in Table II.

TABLE II

Tests Used in the Evaluation of the Experimental Fabrics

A. Composition and Construction of Fabrics

		Federal Standards No.	ASTM or AATCC Method
1.	Fiber Content	2102	
2.	Polyester indentification*		
3.	Yarns/inch	5050	ASTM D-1910
4.	Polyester denier*		
5.	Yarn count	4052	ASTM- 1423
6.	Yarn twist (singles and ply)	4054 (Singles)	ASTM- 1422
		4052 (ply)	ASTM- 1423
7.	Fabric Construction	5041	ASTM-D-1910

B. Fabric Properties

		Federal Standards No.	ASTM or AATCC Method
1.	Fabric thickness	5030	ASTM-D-1777
2.	Air-Flow Permeability	5450.1	ASTM D- 737
3.	Bending length	5202	ASTM D-1388
4.	Drape	5206.1	
5.	Monsanto Wrinkle Recovery	5212	ASTM D-1295
6.	Moisture regain	600	ASTM D- 629
7.	Abrasion of Textile fabric		ASTM D-1175
8.	Stoll flex abrasion	5300	
9.	Color change due to Flat abrasion (Frosting)		AATCC 119-1970
10.	Impeller Tumble Test		AATCC 93-1967
			ASTM D-1175
11.	Breaking strength (Grab method)	5100	ASTM D-1682
12.	Tension Test - Breaking strength-Ravel	5104	ASTM D-1682
13.	Fabric shrinkage		

C. Color and Color Fastness

	Federal Standards No.	ASTM or AATCC Method
1. Color*		
2. Color fastness to wet dry-cleaning	5622	AATCC 85
3. Color fastness to crocking	5651	AATCC 8
4. Color fastness to light	5660	AATCC 16
5. Color fastness to perspiration	5680	AATCC 15

*1. polyester indentification - extraction and staining technique developed at Georgia Tech.
2. polyester denier - Vibrascope measurements
3. color measurement - Diano instrument (latest modification of Color-Eye)

In addition to these standard tests, additional tests were performed to assess the abrasion properties of the fabrics e.g.

1. Multiple tests to determine color change due to flat abrasion (frosting)

2. Random tumble pilling tests on both singed and unsinged fabric

3. Flat-abrasion tests after dry-cleaning 10,20,and 30 times using two dry-cleaning solvents, namely stoddard solvent and perchloroethylene.

IV. Experimental Results and Discussion

In the presentation of experimental data, reference is made to Table I which includes a description of the experimental fabrics. Most of the experimental results are presented using Table I, as a format. The data included in the following tables are mean values, the number of tests which were made to arrive at these mean values are in accord with the standard test methods used. In the statistical analysis of the data, all of the individual test results were used to determine the significance of the differences between mean values.

A. Composition and Construction of Fabrics

1. Fiber Content (Federal Test Method Standard 191-2102)

The results of the analysis of the fabrics for their fiber content are shown in Table III. For the experimental fabrics made to have a composition of 40/60 polyester/wool, the percent polyester was 40.2 to 41.5 and for those fabrics made to have a composition of 60/40 polyester/wool, the percent polyester was 60.4 to 62.4. Thus, it is concluded that the fiber contents of the experimental fabrics were in substantial agreement with the target values. The Air Force Standard fabric had a composition 58.0/42.0 polyester/wool in conformance with MIL-C-21115G.

2. Identification of Polyester Fiber.

The basis for determining the type of polyester in the experimental fabrics was the difference in the dyeing behavior of Dacron 54 and Dacron 64, the latter being dyeable with cationic dyes. Samples of the fabrics were first extracted with a 5 percent solution of soduim hypochlorite, resulting in a complete removal of the wool component. The extracted samples were then treated with an agueous solution of sodium bisulfite, followed by through rinsing and drying. The dye was then removed from the polyester component by Soxhlet extraction with chloroform. After drying, the samples were dyed with a cationic dye, Sevron Blue 2 G (duPont). Dacron 54 and Dacron 35 fibers in fabrics 2,4,6,8,9,10,11, and 12 were only stained whereas fabrics 1,3,5,7 containing Dacron 64 were dyed to a medium blue shade. The dyeing results were in complete agreement with the dyeing results found for the original, undyed polyester fibers. Similar analyses of the various Air Force standard fabrics and a worn Air Force uniform which exhibited severe frosting were made with the following results:

	Dyeing Results
Tropical Standard No. 1 (9 oz. fabric)	Not cationic dyeable

TABLE III

Test Method: 191-2102

FIBER CONTENT

Polyester	Wool	40/60 Polyester/Wool Sample No.	40/60 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results
			PET / WOOL		PET / WOOL		PET / WOOL
Dacron Type 64 3.0 d.p.f.	64s	5-15	40.6/59.4	1-12C	60.8/39.2		
	64s-70s	3-15C	40.2/59.8	7-12	60.4/39.6		
Dacron Type 54 3.0 d.p.f.	64s	2-12C	41.5/58.5	6-15	62.4/37.6	9-12	62.0/38.0
						10-18	61.8/38.2
	64s-70s	8-12	40.5/59.5	4-15C	61.3/38.7		
Dacron Type 54, 4.5 d.p.f./64s wool				11-15	62.4/37.6		
Dacron Type 35, 3.0 d.p.f./64s wool				12-15	59.7/40.3		
Air Force Tropical Standard No. 1					58.0/42.0		
Air Force Tropical Standard No. 2							
Air Force Gabardine Standard							
Air Force Serge Standard							

	Dyeing Results Cont'd
Tropical Standard No. 2 (9 oz. fabric)	Cationic dyeable
Tropical Standard No. 3 (10 oz. fabric)	Cationic dyeable
Serge Standard No. 1	Cationic dyeable
Serge Standard No. 2	Cationic dyeable
Gabardine Standard	Cationic dyeable
Worn Air Force Uniform (frosted)	Cationic dyeable

3. Denier of Polyester Fiber (Vibrascope Method)

The deniers of the dyed fibers used to prepare the experimental fabrics were determined using the Vibrascope method. The results are shown in Table IV.

TABLE IV

Single Filament Denier of Dyed Fibers

Fiber	Denier	C.V.%
Dacron 35 (3.0 denier)	3.22	11
Dacron 54 (3.0 denier)	3.00	12
Dacron 54 (4.5 denier)	4.93	12
Dacron 64 (3.0 denier)	3.30	10
Wool (64's)	5.43	29
Woll (64's-70's)	5.64	25

It is noted that the denier of 64s -70s wool is significantly different from that for 64s wool. 64s -70s wool should have given a lower value than 64s wool.

4. Yarn Count and Yarn Twist (Federal Test Method Standard 191-4052, 4054)

The target for the yarn worsted count for all of the fabrics was 40s/2 or equivalent to 20s singles worsted count. The yarn twist was 12,15 and 18 t.p.i. in both the singles and ply yarns. The results of the analysis of the yarns used are given in Tables V and VI.

With the exception of yarn Y5, the equivalent singles count lie between 18.7 and 21.1. The low value for Y_5 was due to an error made by the yarn spinner. It is noted that the ply twist is in all cases slightly greater than the twist in the singles. This is common commercial practice for such yarns. Those yarns targeted to have a twist of 12 t.p.i, were actually found to have a twist in the singles of 11.0 to 11.5 tpi and a twist of 12.8 to 13.4 tpi in the ply. Those yarns targeted to have a twist of 15 tpi, were found to have a twist of 13.7 to 14.1 in the singles and 15.4 to 16.0 in the ply. It is concluded that the yarns met the required yarn twist values.

5. Fabric Construction Fabric Weight and Warp and Filling Yarns per inch (Federal Test Method Standard 191-5041).

The target values for the warp and filling yarns per inch were 54 and 42 respectively to produce a fabric having weight of 5.8 oz / yd^2 corresponding to a 9.0 oz. fabric based on a 56 inch wide fabric. The results of the analysis of the experimental fabrics are shown in Tables VII and VIII. Most of the fabrics are heavier than the 9.0 oz. standard fabric but their weights are nearly within the allowable limits described in MIL-C-21115G with the exception of fabric Y5. The greater weight of this fabric is due to the coarser yarn used.

B. Fabric Properties

1. Air Permeability- (Federal Test Method Standard 191- 5450.1)

The results of air permeability tests are shown in Table IX. It is concluded that fabrics made from Dacron 54 are slightly more permeable than

TABLE V

Test Method: FED. TEST METHOD STANDARD 191 - 4052, 4054

YARN COUNT (EQUIVALENT SINGLES - WORSTED)

Polyester	Wool	40/60 Polyester/Wool		60/40 Polyester/Wool			
		Sample No.	Results	Sample No.	Results	Sample No.	Results
Dacron Type 64 3.0 d.p.f.	64s	5-15	15.7	1-12C	18.9		
	64s-70s	3-15C	19.6	7-12	19.3		
Dacron Type 54 3.0 d.p.f.	64s	2-12C	19.7	6-15	19.8	9-12	18.7
	64s-70s	8-12	20.6	4-15C	19.5	10-18	20.1
Dacron Type 54, 4.5 d.p.f./64s wool				11-15	20.1		
Dacron Type 35, 3.0 d.p.f./64s wool				12-15	20.1		
Air Force Tropical Standard No. 1					20.0		
Air Force Tropical Standard No. 2							
Air Force Gabardine Standard							
Air Force Serge Standard							

TABLE VI

Test Method: F91-4054; 4052

YARN TWIST

Polyester	Wool	40/60 Polyester/Wool Sample No.	Results P*	Results S*	60/40 Polyester/Wool Sample No.	Results P*	Results S*	Sample No.	Results P*	Results S*
Dacron Type 64 3.0 d.p.f.	64s	5-15	15.9	13.7	1-12C	13.0	11.4			
	64s-70s	3-15C	15.7	13.8	7-12	12.8	11.5			
Dacron Type 54 3.0 d.p.f.	64s	2-12C	13.2	11.0	6-15	15.9	14.1	9-12	13.2	11.5
								10-18	19.9	16.7
	64s-70s	8-12	13.4	11.2	4-15C	15.4	13.8			
Dacron Type 54, 4.5 d.p.f./64s wool					11-15	15.6	13.8			
Dacron Type 35, 3.0 d.p.f./64s wool					12-15	15.7	13.9			
Air Force Tropical Standard No. 1						10.8	10.6			
Air Force Tropical Standard No. 2										
Air Force Gabardine Standard										
Air Force Serge Standard										

* P - ply
S - singles

TABLE VII

Test Method: 191-5041

ENDS AND PICKS PER INCH

Polyester	Wool	40/60 Polyester/Wool Sample No.	Results Ends	Picks	60/40 Polyester/Wool Sample No.	Results Ends	Picks	Sample No.	Results Ends	Picks
Dacron Type 64 3.0 d.p.f.	64s	5-15	56	43	1-12C	57	42			
	64s-70s	3-15C	57	42	7-12	57	44			
Dacron Type 54 3.0 d.p.f.	64s	2-12C	57	42	6-15	56	44	9-12	58	45
								10-18	56	42
	64s-70s	8-12	56	42	4-15C	56	42			
Dacron Type 54, 4.5 d.p.f./64s wool					11-15	55	43			
Dacron Type 35, 3.0 d.p.f./64s wool					12-15	55	43			
Air Force Tropical Standard No. 1						55	45			
Air Force Tropical Standard No. 2										
Air Force Gabardine Standard										
Air Force Serge Standard										

TABLE VIII

Test Method: 191-5041
FABRIC WEIGHT (OZ./YD^2)

Polyester	Wool	40/60 Polyester/Wool Sample No.	40/60 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results
Dacron Type 64 3.0 d.p.f.	64s	5-15	7.5	1-12C	6.0		
	64s-70s	3-15C	6.2	7-12	6.0		
Dacron Type 54 3.0 d.p.f.	64s	2-12C	6.0	6-15	6.3	9-12	6.3
						10-18	6.0
	64s-70s	8-12	5.8	4-15C	6.0		
Dacron Type 54, 4.5 d.p.f./64s wool				11-15	5.6		
Dacron Type 35, 3.0 d.p.f./64s wool				12-15	6.0		
Air Force Tropical Standard No. 1					5.8		
Air Force Tropical Standard No. 2							
Air Force Gabardine Standard							
Air Force Serge Standard							

those made from Dacron 64. Fabrics containing 60 per cent polyester are slightly more permeable than those containing 40 percent polyester. Although yarn twist does not seem to have an affect on permeability with fabrics 1 through 8, the values for fabrics 9,6, and 10 indicate that the permeability does increase with an increase in yarn twist. The fabric containing 4.5 denier Dacron 54 (fabric 11) is somewhat more permeable than the equivalent fabric containing 3.0 denier Dacron 54.

2. Fabric Thickness (Federal Test Method Standard 191-5030)

The fabric thickness values are shown in Table X. With the exception of fabric 5 (made from a too- coarse yarn by mistake), all of the values fall between 0.016 and 0.018 inch compared with a value of 0.015 inch for the Air Force Tropical Standard No. 1.

3. Bending Length (Federal Test Method Standard 191-5202)

Bending length measurements are shown in Table XI. There appear to be only very small differences in bending behavior of the experimental fabrics, all of them being very similar to the Air Force Standard No. 1 fabric.

4. Wrinkle Recovery (Monsanto) (Federal Test Method Standard 191-5212)

The Monsanto wrinkle recovery values are shown in Table XII. There appears to be no significant difference in the wrinkle recovery of the experimental fabrics and the Air Force Tropical Standard fabric.

5. Breaking Strength (Grab and Ravel Strip) (Federal Test Method Standard 191-5100 and 191-5104)

Breaking strength measurements were made on the experimental fabrics by both the grab method and the ravel strip method. The results are shown in Tables XIII and XIV. The only variables examined which had an affect on fabric strength were the type of polyester used and the fiber content of the

TABLE IX

Test Method: 191-5450.1

AIR PERMEABILITY (FT^3/MIN./FT^2)

Polyester	Wool	40/60 Polyester/Wool Sample No.	40/60 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results
Dacron Type 64 3.0 d.p.f.	64s	5-15	38	1-12C	55		
	64s-70s	3-15C	39	7-12	51		
Dacron Type 54 3.0 d.p.f.	64s	2-12C	41	6-15	69	9-12	42
	64s-70s	8-12	61	4-15C	64	10-18	120
Dacron Type 54, 4.5 d.p.f./64s wool				11-15	91		
Dacron Type 35, 3.0 d.p.f./64s wool				12-15	73		
Air Force Tropical Standard No. 1					39		
Air Force Tropical Standard No. 2							
Air Force Gabardine Standard							
Air Force Serge Standard							

TABLE X

Test Method: 191-5030

FABRIC THICKNESS (IN.)

Polyester	Wool	40/60 Polyester/Wool Sample No.	40/60 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results
Dacron Type 64 3.0 d.p.f.	64s	5-15	0.023	1-12C	0.017		
	64s-70s	3-15C	0.016	7-12	0.018		
Dacron Type 54 3.0 d.p.f.	64s	2-12C	0.016	6-15	0.018	9-12	0.018
						10-18	0.017
	64s-70s	8-12	0.017	4-15C	0.016		
Dacron Type 54, 4.5 d.p.f./64s wool				11-15	0.016		
Dacron Type 35, 3.0 d.p.f./64s wool				12-15	0.016		
Air Force Tropical Standard No. 1					0.015		
Air Force Tropical Standard No. 2							
Air Force Gabardine Standard							
Air Force Serge Standard							

TABLE XI

Test Method: 191 - 5202

BENDING LENGTH (CM.)

Polyester	Wool	40/60 Polyester/Wool Sample No.	40/60 Results W*	40/60 Results F*	60/40 Polyester/Wool Sample No.	60/40 Results W*	60/40 Results F*	Sample No.	Results W*	Results F*
Dacron Type 64 3.0 d.p.f.	64s	5-15	2.23	2.17	1-12C	2.16	1.90			
	64s-70s	3-15C	1.98	1.81	7-12	2.06	1.89			
Dacron Type 54 3.0 d.p.f.	64s	2-12C	207	1.86	6-15	2.17	2.01	9-12	2.13	2.08
								10-18	2.29	1.91
	64s-70s	8-12	203	2.16	4-15C	2.11	1.90			
Dacron Type 54, 4.5 d.p.f./64s wool					11-15	2.31	2.09			
Dacron Type 35, 3.0 d.p.f./64s wool					12-15	2.24	2.05			
Air Force Tropical Standard No. 1						2.22	2.04			
Air Force Tropical Standard No. 2										
Air Force Gabardine Standard										
Air Force Serge Standard										

* W - WARP
F - FILLING

TABLE XII

Test Method: 191-5212
MONSANTO WRINKLE RECOVERY (%)

Polyester	Wool	40/60 Polyester/Wool Sample No.	40/60 Results W*	40/60 Results F*	60/40 Polyester/Wool Sample No.	60/40 Results W*	60/40 Results F*	60/40 Sample No.	60/40 Results W*	60/40 Results F*
Dacron Type 64 3.0 d.p.f.	64s	5-15	87	87	1-12C	83	85			
	64s-70s	3-15C	86	86	7-12	88	83			
Dacron Type 54 3.0 d.p.f.	64s	2-12C	87	87	6-15	86	85	9-12	88	84
	64s-70s	8-12	91	86	4-15C	89	81	10-18	92	86
Dacron Type 54, 4.5 d.p.f./64s wool					11-15	87	85			
Dacron Type 35, 3.0 d.p.f./64s wool					12-15	88	86			
Air Force Tropical Standard No. 1						94	87			
Air Force Tropical Standard No. 2										
Air Force Gabardine Standard										
Air Force Serge Standard										

* W- WARP
F- FILLING

TABLE XIII

Test Method: 191-5100

BREAKING STENGTH - GRAB - (LBS.)

Polyester	Wool	40/60 Polyester/Wool Sample No.	Results W*	Results F*	60/40 Polyester/Wool Sample No.	Results W*	Results F*	Sample No.	Results W*	Results F*
Dacron Type 64 3.0 d.p.f.	64s	5-15	154	106	1-12C	134	97			
	64s-70s	3-15C	117	81	7-12	131	102			
Dacron Type 54 3.0 d.p.f.	64s	2-12C	173	119	6-15	196	156	9-12	211	157
								10-18	206	146
	64s-70s	8-12	168	108	4-15C	175	138			
Dacron Type 54, 4.5 d.p.f./64s wool					11-15	201	148			
Dacron Type 35, 3.0 d.p.f./64s wool					12-15	159	122			
Air Force Tropical Standard No. 1										
Air Force Tropical Standard No. 2										
Air Force Gabardine Standard										
Air Force Serge Standard										

* WARP
FILLING

TABLE XIV

Test Method: 191-5104

BREAKING STRENGTH - RAVEL - (LBS./IN.)

Polyester	Wool	40/60 Polyester/Wool Sample No.	Results W*	Results F*	60/40 Polyester/Wool Sample No.	Results W*	Results F*	Sample No.	Results W*	Results F*
Dacron Type 64 3.0 d.p.f.	64s	5-15	87	66	1-12C	84	61			
	64s-70s	3-15C	68	50	7-12	83	65			
Dacron Type 54 3.0 d.p.f.	64s	2-12C	94	69	6-15	127	97	9-12	126	101
								10-18	124	94
	64s-70s	8-12	96	72	4-15C	110	87			
Dacron Type 54, 4.5 d.p.f./64s wool					11-15	119	93			
Dacron Type 35, 3.0 d.p.f./64s wool					12-15	101	77			
Air Force Tropical Standard No. 1						109				
Air Force Tropical Standard No. 2										
Air Force Gabardine Standard										
Air Force Serge Standard										

* W - WARP
F - FILLING

fabrics. Fabrics containing Dacron 54 were appreciably stronger than those containing Dacron 64. The fabric containing Dacron 35 was immediate in strength. These results are consistent with the single filament strength data. An increase in the polyester content from 40 to 60 percent results in an increase in strength. In all cases the fabrics had strengths greater than the minimum strength required in MIL-C-21115G.

6. Random Tumble Pilling Test (ASTM-D-1375-72)

According to MIL-C-21115G, the pilling test specified is Federal Test Method Standard 191-5320, which is the sponge-brush pilling test. In this work the pilling test used was the random tumble test described in ASTM Method D-1375-72. The fabrics were tested before and after they had been singed. The results are shown in Tables XV and XVI. For the unsinged fabrics, it is concluded that fabrics containing Dacron 64 show much less pilling than those containing Dacron 54 particularly when the test was run for 60 minutes. For the singed fabrics, there appears to be no difference between fabrics containing the two polyester fibers.

7. Impeller Tumbler Test (Accelerotor Method) (AATCC-93-1967)

In this method, the abrasion of the fabrics results in a loss in the fabric weight. From the data in Table XVII, it is concluded that the only factor which affects the weight loss is the fiber content, a somewhat greater loss in weight shown for fabrics containing 60 percent wool. This was an expected result due to the fact that wool fibers have less strength than polyester fibers.

8. Stoll Flex Abrasion (Federal Test Method Standard 191-5300)

The mean values for the cycles to rupture by this method are shown in Table XVIII. The only obvious conclusion is that fabrics containing Dacron 54 are better than those containing Dacron 64 indicative of the greater toughness of Dacron 54.

TABLE XVIII

Test Method: FED. TEST METHOD STANDARD - 191-5300

STOLL FLEX ABRASION - CYCLES TO RUPTURE

Polyester	Wool	40/60 Polyester/Wool Sample No.	40/60 Results W*	40/60 Results F*	60/40 Polyester/Wool Sample No.	60/40 Results W*	60/40 Results F*	60/40 Sample No.	60/40 Results W*	60/40 Results F*
Dacron Type 64 3.0 d.p.f.	64s	5-15	1190	1290	1-12C	1560	2520			
	64s-70s	3-15C	1510	1660	7-12	1110	1100			
Dacron Type 54 3.0 d.p.f.	64s	2-12C	4090	3810	6-15	2740	2360	9-12	1510	2390
	64s-70s	8-12	2720	2330	4-15C	5300	5140	10-18	2360	2380
Dacron Type 54, 4.5 d.p.f./64s wool					11-15	3310	2950			
Dacron Type 35, 3.0 d.p.f./64s wool					12-15	1550	1660			
Air Force Tropical Standard No. 1										
Air Force Tropical Standard No. 2										
Air Force Gabardine Standard										
Air Force Serge Standard										

* W WARP

F FILLING

TABLE XV

Test Method: ASTM D-1375-72
RANDOM TUMBLE PILLING TEST
(NOT SINGED)

Polyester	Wool	40/60 Polyester/Wool Sample No.	Results 30 MIN	Results 60 MIN	60/40 Polyester/Wool Sample No.	Results 30 MIN.	Results 60 MIN.	Sample No.	Results 30 MIN.	Results 60 MIN.
Dacron Type 64 3.0 d.p.f.	64s	5-15	5.0	5.0	1-12C	3.5	4.0			
	64s-70s	3-15C	4.5	5.0	7-12	3.5	4.0			
Dacron Type 54 3.0 d.p.f.	64s	2-12C	3.5	3.0	6-15	3.5	2.5	9-12	3.5	2.5
								10-18	3.5	3.0
	64s-70s	8-12	4.0	3.0	4-15C	3.5	2.5			
Dacron Type 54, 4.5 d.p.f./64s wool					11-15	4.0	3.5			
Dacron Type 35, 3.0 d.p.f./64s wool					12-15	3.5	4.5			
Air Force Tropical Standard No. 1										
Air Force Tropical Standard No. 2										
Air Force Gabardine Standard										
Air Force Serge Standard										

TABLE XVI

Test Method: ASTM - D-1375-72
RANDOM TUMBLE PILLING TEST
(SINGED)

Polyester	Wool	40/60 Polyester/Wool Sample No.	Results 30 MIN	Results 60 MIN	60/40 Polyester/Wool Sample No.	Results 30 MIN	Results 60 MIN	Sample No.	Results 30 MIN	Results 60 MIN
Dacron Type 64 3.0 d.p.f.	64s	5-15	4.5	4.5	1-12C	4.0	4.0			
	64s-70s	3-15C	4.0	4.0	7-12	4.0	4.0			
Dacron Type 54 3.0 d.p.f.	64s	2-12C	4.5	4.0	6-15	4.5	4.0	9-12	4.0	3.0
								10-18	4.0	4.0
	64s-70s	8-12	4.0	4.0	4-15C	4.5	3.0			
Dacron Type 54, 4.5 d.p.f./64s wool					11-15	4.5	4.5			
Dacron Type 35, 3.0 d.p.f./64s wool					12-15	4.5	4.5			
Air Force Tropical Standard No. 1						4.5	4.0			
Air Force Tropical Standard No. 2						4.0	4.0			
Air Force Gabardine Standard										
Air Force Serge Standard						4.0	4.0			

TABLE XVII

Test Method: AATCC 93-1967
IMPELLER TUMBLE TEST (ACCELEROTOR METHOD)
WEIGHT LOSS (%) 5 MIN, 3000 R.P.M.

Polyester	Wool	40/60 Polyester/Wool Sample No.	40/60 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results
			WT LOSS %		WT LOSS %		WT LOSS %
Dacron Type 64 3.0 d.p.f.	64s	5-15	4.14	1-12C	3.87		
	64s-70s	3-15C	4.50	7-12	3.66		
Dacron Type 54 3.0 d.p.f.	64s	2-12C	4.39	6-15	3.57	9-12	2.61
						10-18	2.55
	64s-70s	8-12	4.06	4-15C	2.44		
Dacron Type 54, 4.5 d.p.f./64s wool				11-15	2.90		
Dacron Type 35, 3.0 d.p.f./64s wool				12-15	3.09		
Air Force Tropical Standard No. 1					4.27		
Air Force Tropical Standard No. 2							
Air Force Gabardine Standard					3.59		
Air Force Serge Standard					5.26		

9. Color Change due to Flat Abrasion (Frosting) (AATCC Method 119-1970)

A considerable amount of work was devoted to an evaluation of the fabrics with respect to color change due to flat abrasion. The standard A.A.T.C.C. method used is the only standard method available and designed for the assessment of fabric frosting. This method employs a Stoll Universal Abrader with the flat-abrasion attachment. The abradent is a standard stainless steel wire screen and the head load is 2.5 lbs. The procedure requires that the fabric specimen be abraded for 1200 cycles, after which the sample is rinsed in luke-warm water and dried. The degree of color change due to abrasion is determined by reference to the A.A.T.C.C. Geometric Grey Scale for assessing color change.

In order to obtain the maximum amount of information about the experimental fabrics as well as the Air Force Standard fabrics, five different levels of abrasion were used, 1200, 2400, 4800, 7200, and 9600 cycles. The abraded fabrics were evaluated for color change by five (5) observers. The angle of viewing was 45° with respect to the fabric surface and the light source was a MacBeth daylight lamp. The experimental results (mean values for ratings) are shown in Tables XVIX-XXIII. In order to determine the reproducibility of the abrasion test, a second set of samples were abraded for 4800 cycles. Comparison of the results obtained with the previous 4800 cycle test is shown in Table XXIV. When the samples were abraded for 1200 cycles, no differences between samples and standard fabrics were noted. However, with increasing severity of the abrasion, the variable which is most significant in frosting is the type of polyester used. Dacron 54 containing fabrics showed significantly less frosting than Dacron 64 containing fabrics. The fabric containing 4.5 denier Dacron 54 (No.11) showed a slightly less color change on abrasion than its control fabric (No. 6) containing 3.0

TABLE XVIX

Test Method: AATCC 119-1970

COLOR CHANGE DUE TO FLAT ABRASION (FROSTING)
1200 CYCLES

Polyester	Wool	40/60 Polyester/Wool		60/40 Polyester/Wool			
		Sample No.	Results	Sample No.	Results	Sample No.	Results
			RATING*		RATING*		RATING*
Dacron Type 64 3.0 d.p.f.	64s	5-15	4.9	1-12C	5.0		
	64s-70s	3-15C	5.0	7-12	5.0		
Dacron Type 54 3.0 d.p.f.	64s	2-12C	4.9	6-15	5.0	9-12	5.0
						10-18	5.0
	64s-70s	8-12	5.0	4-15C	5.0		
Dacron Type 54, 4.5 d.p.f./64s wool				11-15	5.0		
Dacron Type 35, 3.0 d.p.f./64s wool				12-15	5.0		
Air Force Tropical Standard No. 1							
Air Force Tropical Standard No. 2					4.9		
Air Force Gabardine Standard							
Air Force Serge Standard					5.0		

* GEOMETRIC GREY SCALE

TABLE XX

Test Method: AATCC 119-1970

COLOR CHANGE DUE TO FLAT ABRASION (FROSTING)

2400 cycles

Polyester	Wool	40/60 Polyester/Wool		60/40 Polyester/Wool			
		Sample No.	Results	Sample No.	Results	Sample No.	Results
			RATING		RATING		RATING
Dacron Type 64 3.0 d.p.f.	64s	5-15	4.3	1-12C	4.8		
	64s-70s	3-15C	4.4	7-12	4.9		
Dacron Type 54 3.0 d.p.f.	64s	2-12C	4.7	6-15	4.9	9-12	5.0
	64s-70s	8-12	4.7	4-15C	5.0	10-18	5.0
Dacron Type 54, 4.5 d.p.f./64s wool				11-15	4.9		
Dacron Type 35, 3.0 d.p.f./64s wool				12-15	4.9		
Air Force Tropical Standard No. 1							
Air Force Tropical Standard No. 2					4.5		
Air Force Gabardine Standard							
Air Force Serge Standard					5.0		

* GEOMETRIC GREY SCALE -

TABLE XXI

Test Method: AATCC 119-1970
COLOR CHANGE DUE TO FLAT ABRASION (FROSTING)
4800 CYCLES

Polyester	Wool	40/60 Polyester/Wool Sample No.	40/60 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results
			RATING*		RATING*		RATING*
Dacron Type 64 3.0 d.p.f.	64s	5-15	3.9	1-12C	4.1		
	64s-70s	3-15C	4.0	7-12	4.0		
Dacron Type 54 3.0 d.p.f.	64s	2-12C	4.5	6-15	4.5	9-12	4.4
						10-18	4.5
	64s-70s	8-12	4.5	4-15C	4.4		
Dacron Type 54, 4.5 d.p.f./64s wool				11-15	4.6		
Dacron Type 35, 3.0 d.p.f./64s wool				12-15	4.1		
Air Force Tropical Standard No. 1							
Air Force Tropical Standard No. 2					3.6		
Air Force Gabardine Standard							
Air Force Serge Standard					4.6		

* GEOMETRIC GREY SCALE

TABLE XXII

Test Method: AATCC 119-1970

COLOR CHANGE DUE TO FLAT ABRASION (FROSTING)

7200 CYCLES

Polyester	Wool	40/60 Polyester/Wool		60/40 Polyester/Wool			
		Sample No.	Results RATING*	Sample No.	Results RATING*	Sample No.	Results RATING*
Dacron Type 64 3.0 d.p.f.	64s	5-15	3.3	1-12C	3.5		
	64s-70s	3-15C	3.6	7-12	3.4		
Dacron Type 54 3.0 d.p.f.	64s	2-12C	4.1	6-15	4.0	9-12	4.3
						10-18	4.2
	64s-70s	8-12	4.4	4-15C	4.5		
Dacron Type 54, 4.5 d.p.f./64s wool				11-15	4.5		
Dacron Type 35, 3.0 d.p.f./64s wool				12-15	3.8		
Air Force Tropical Standard No. 1							
Air Force Tropical Standard No. 2					3.3		
Air Force Gabardine Standard							
Air Force Serge Standard					4.2		

* GEOMETRIC GREY SCALE

TABLE XXIII

Test Method: AATCC 119-1970

COLOR CHANGE DUE TO FLAT ABRASION (FROSTING)

9600 CYCLES

Polyester	Wool	40/60 Polyester/Wool Sample No.	40/60 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results	Sample No.	Results
			RATING*		RATING*		RATING*
Dacron Type 64 3.0 d.p.f.	64s	5-15	3.0	1-12C	3.1		
	64s-70s	3-15C	3.4	7-12	3.2		
Dacron Type 54 3.0 d.p.f.	64s	2-12C	3.5	6-15	4.0	9-12	3.3
	64s-70s	8-12	3.8	4-15C	4.3	10-18	3.1
Dacron Type 54, 4.5 d.p.f./64s wool				11-15	4.1		
Dacron Type 35, 3.0 d.p.f./64s wool				12-15	3.1		
Air Force Tropical Standard No. 1							
Air Force Tropical Standard No. 2					2.9		
Air Force Gabardine Standard							
Air Force Serge Standard					3.0		

* GEOMETRIC GREY SCALE

TABLE XXIV

Test Method: AATCC 119-1970

COLOR CHANGE DUE TO FLAT ABRASION (FROSTING)

4800 CYCLES (DUPLICATE RUN)

Polyester	Wool	40/60 Polyester/Wool Sample No.	40/60 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results	60/40 Polyester/Wool Sample No.	60/40 Polyester/Wool Results
			RATING*		RATING*		RATING*
Dacron Type 64 3.0 d.p.f.	64s	5-15	4.2 3.9	1-12C	4.1 4.1		
	64s-70s	3-15C	4.4 4.0	7-12	4.0 4.0		
Dacron Type 54 3.0 d.p.f.	64s	2-12C	4.5 4.5	6-15	4.6 4.5	9-12	4.5 4.4
						10-18	4.4 4.5
	64s-70s	8-12	4.5 4.5	4-15C	4.8 4.4		
Dacron Type 54, 4.5 d.p.f./64s wool				11-15	4.7 4.6		
Dacron Type 35, 3.0 d.p.f./64s wool				12-15	4.1 4.1		
Air Force Tropical Standard No. 1					4.5		
Air Force Tropical Standard No. 2					4.1 3.6		
Air Force Gabardine Standard							
Air Force Serge Standard					4.4 4.6		

* GEOMETRIC GREY SCALE

denier Dacron 54. The fabric containing Dacron 35 showed a degree of frosting intermediate between that of Dacron 54 and Dacron 64. The two Air Force Tropical Standard fabrics differed in their degree of frosting. This difference is shown only in Table XXIV, the Tropical Standard No. 1 showing less frosting than the Tropical Standard No. 2. The No. 1 Standard resembles the experimental fabrics containing Dacron 54 in its abrasion behavior, whereas the No. 2 Standard resembles the experimental fabrics containing Dacron 64. It should be recalled that staining tests performed on these two fabrics indicated that the polyester component of the No. 1 Standard is not cationic dyeable and therefore not chemically like Dacron 64 whereas the polyester component of the No. 2 Standard is cationic dyeable like Dacron 64. These results prove that, in the past, uniform fabrics have been made from fibers having a chemical composition corresponding to the poly(ethyleneterephthalate) homopolymer as well as those corresponding to a chemically modified poly(ethyleneterephthalate) polymer. In the latter case, the kind of chemical modification is one which provides dye sites for the absorption of cationic dyes. This modified fiber is sold as a pill-resistant fiber.

In order to obtain a quantitave assessment of the color change due to abrasion, color measurements were made using the Diano LSCE instrument. Two methods were used. In one method, the tristimulus values were determined for the abraded sample and its unabraded reference sample using $BaSO_4$ as a reference. Due to the fact that the values obtained are very low by this method, a second method was used in which the abraded sample was placed in the reference port of the instrument and the unabraded sample was placed in the sample port. This method is preferred for the measurement of small color differences for dark samples similar to the Air Force fabric. The color change for each fabric due to abrasion was calculated and expressed in terms of the total color difference, ΔE, the hue difference ΔC and the lightness difference ΔL, the unit for each being Mac Adam color difference units. It is well known that there are several factors which contribute to the observed color differences. The difference in the depth of shade of the two fiber components is one factor. Another factor which cannot be ignored is the degree of penetration of the dye in each of two fiber components. In the case of the experimental fabrics both fiber components are penetrated by dye and, therefore, any color change observed on abrasion is not associated with poor dye penetration. With respect to the difference in depth of shade of the two fiber components, the wool component in the Dacron 64/wool blend fabrics is slightly lighter in shade than the Dacron 64 component. The reverse is true for the Dacron 54 (3.0 denier)/wool fabrics. Since the wool component is preferentially worn away on abrasion, it would be expected that the color change on abrasion for the Dacron 64/wool fabric would be less apparent than that for the Dacron 54/wool fabrics, assuming both polyester fibers had the same abrasion resistance. The reverse of this was found indicating that Dacron 64 is much less abrasion resistant than Dacron 54.

The results of color difference measurments made on the abraded experimental fabrics are shown in Figs. 1-15. As was expected , the overall color difference ΔE gives the best agreement with the visual assessment of color change.

The results of the flat-abrasion tests lead to the following conclusions:

1. The superiority in resistance to frosting of Dacron type 54 compared to Dacron type 64 and Dacron type 35.

2. Small improvement in resistance to frosting obtained by using a 4.5 denier Dacron type 54 rather than a 3.0 denier Dacron type 54.

3. The necessity for fabric singeing to obtain good pilling resistance.

4. The slightly better resistance to frosting afforded by a 60/40 polyester/wool blend fabric compared to a 40/60 polyester/wool blend fabric.

The other variables included in the experimental design, namely, car-

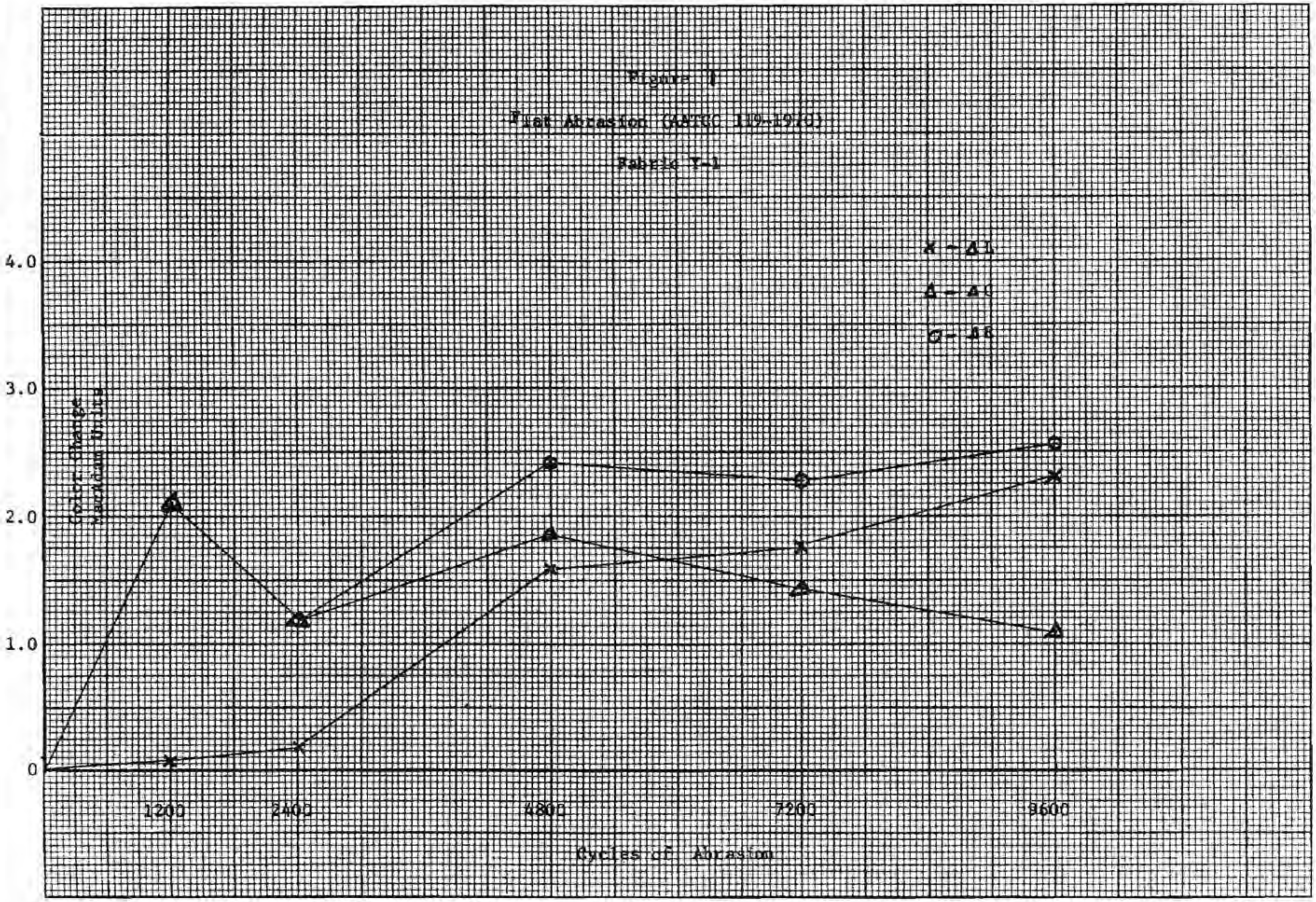


Figure
Flat Abrasion (AATCC 119-1970)
Fabric Y-1
Color Change
MacAdam Units
4.0
3.0
2.0
1.0
0
1200
2400
4800
7200
9600
Cycles of Abrasion

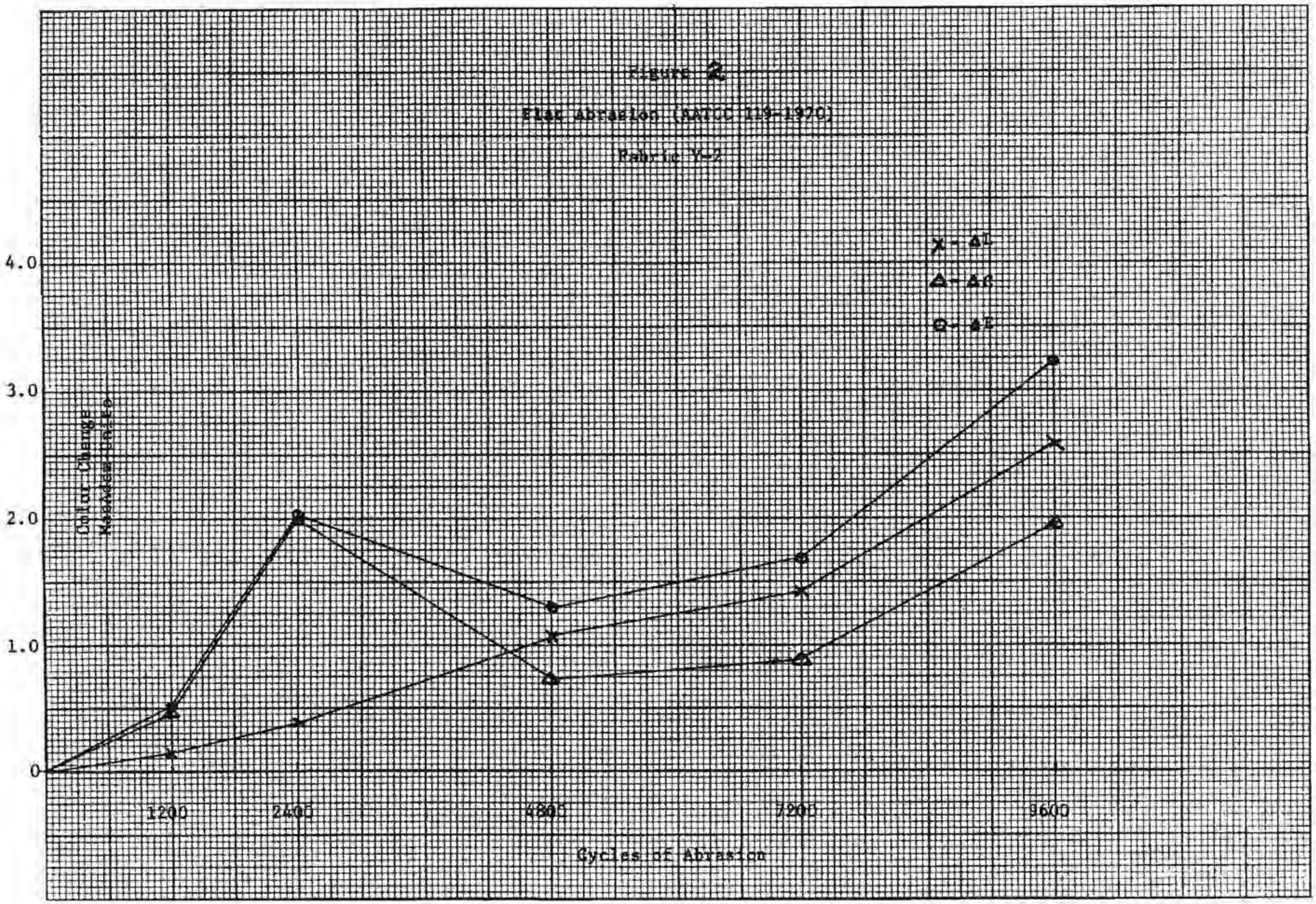


Figure 2

Flex Abrasion (AATCC 119-1970)

Fabric Y-2

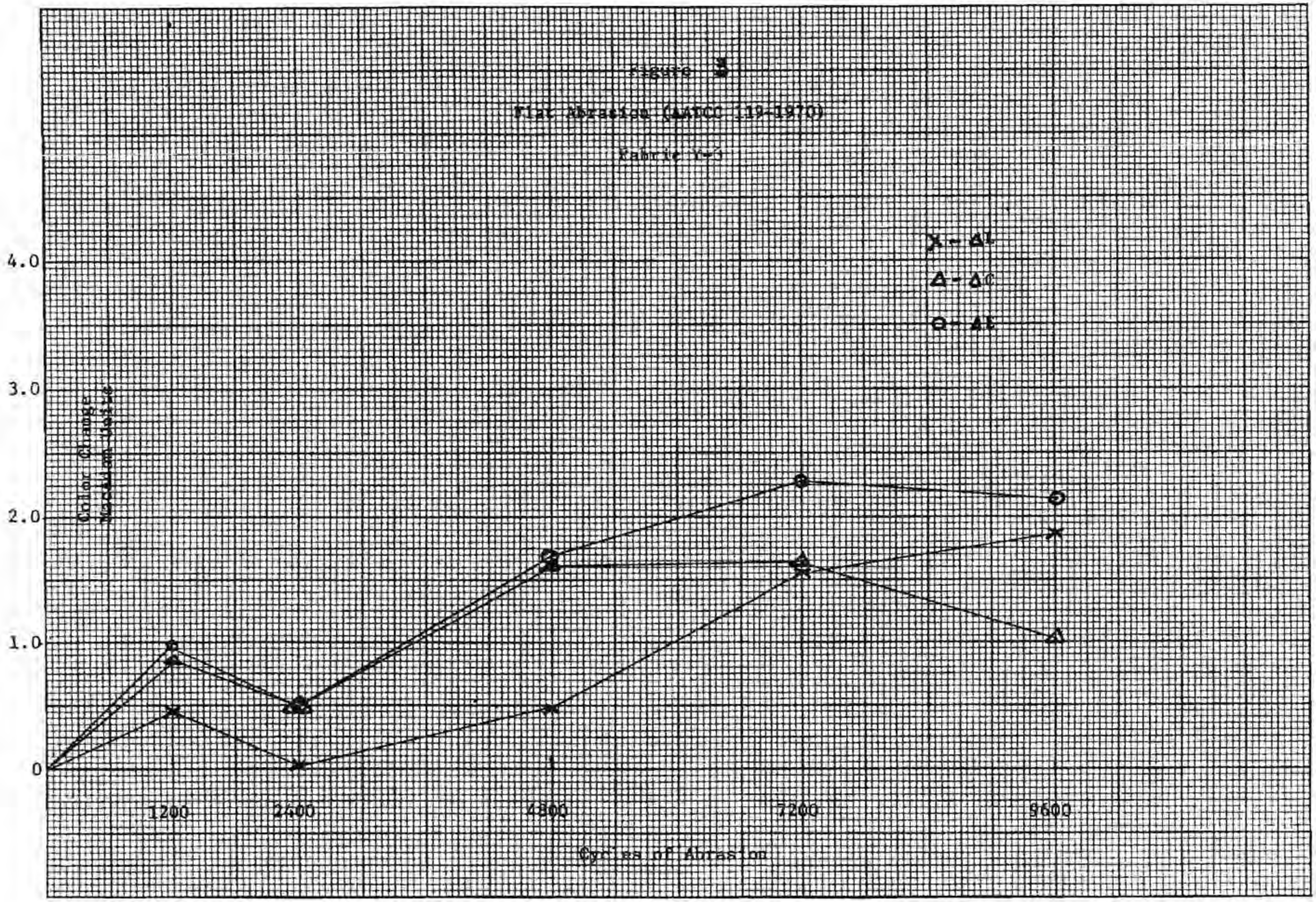
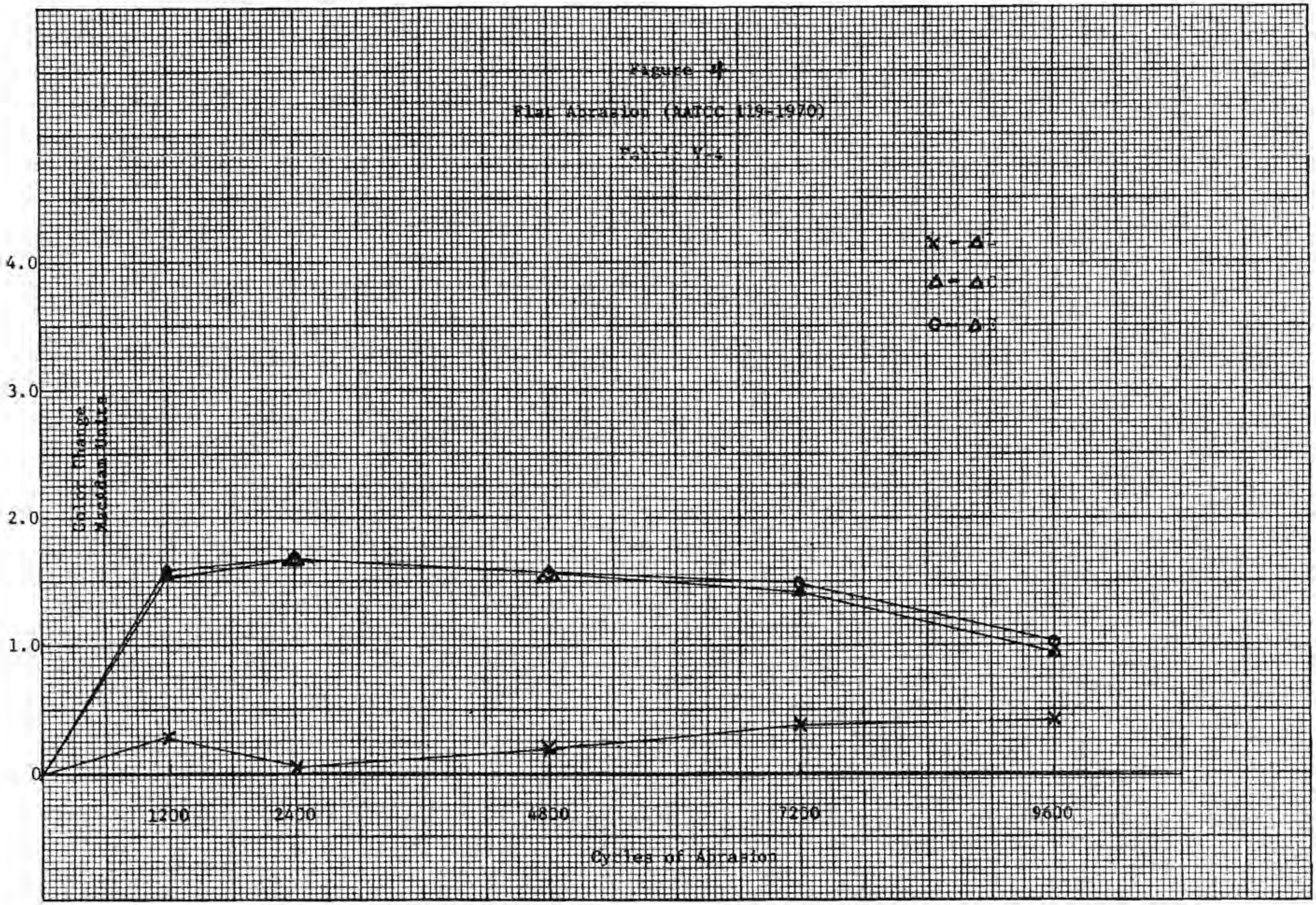


Figure
Flat Abrasion (AATCC 119-1970)
Fabric Y-3
X - ΔL
Δ - ΔC
O - ΔE
Color Change
4.0
3.0
2.0
1.0
0
1200
2400
4800
7200
9600
Cycles of Abrasion


Flat Abrasion (AATCC 119-1970)
4.0
3.0
2.0
1.0
0
Color Change
1200
2400
4800
7200
9600
Cycles of Abrasion

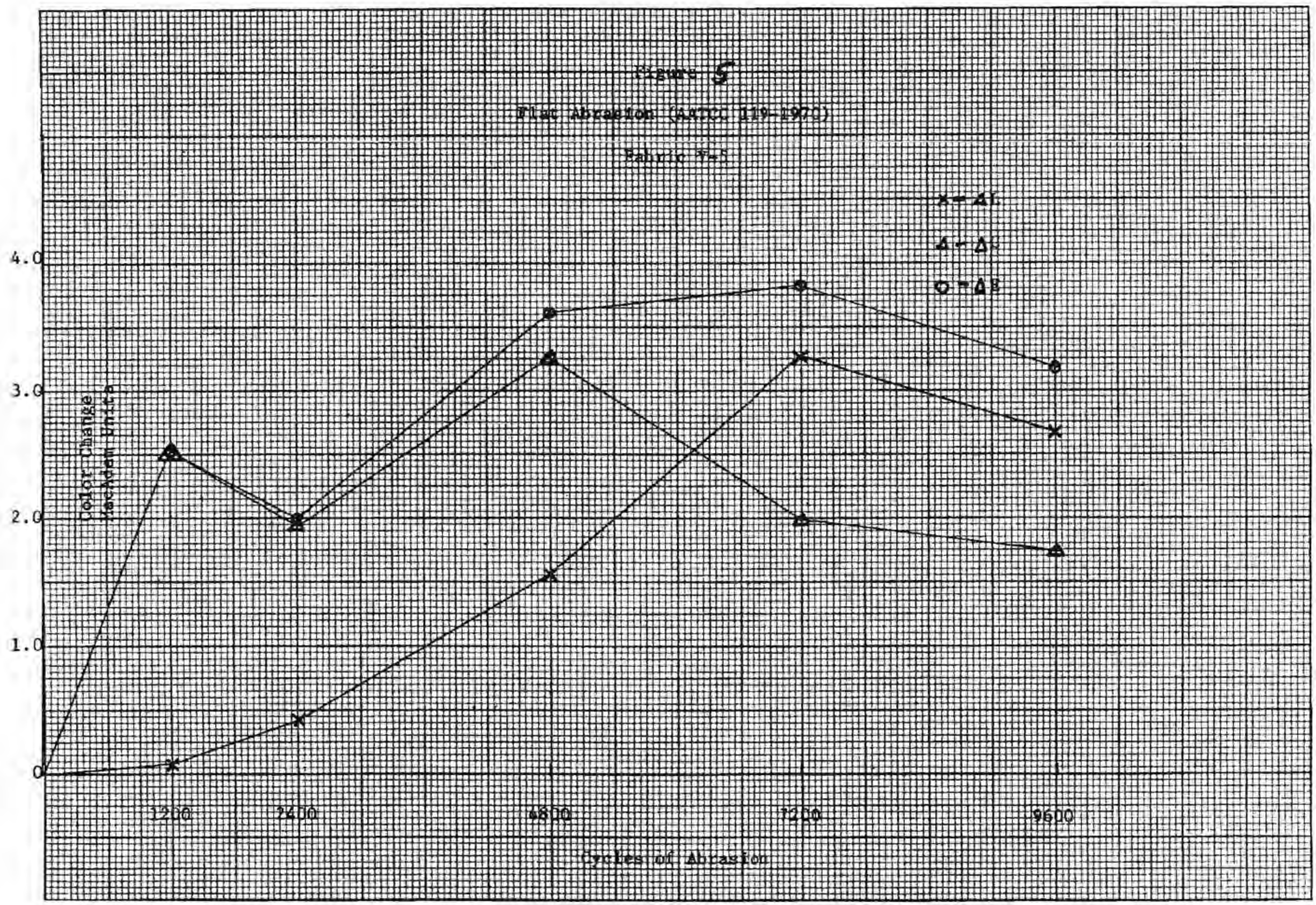


Figure 5
Flat Abrasion (AATCC 119-1970)
Fabric V-5
X = ΔL
Δ = ΔA
O = ΔB
Color Change
MacAdam Units
4.0
3.0
2.0
1.0
0
1200
2400
4800
7200
9600
Cycles of Abrasion

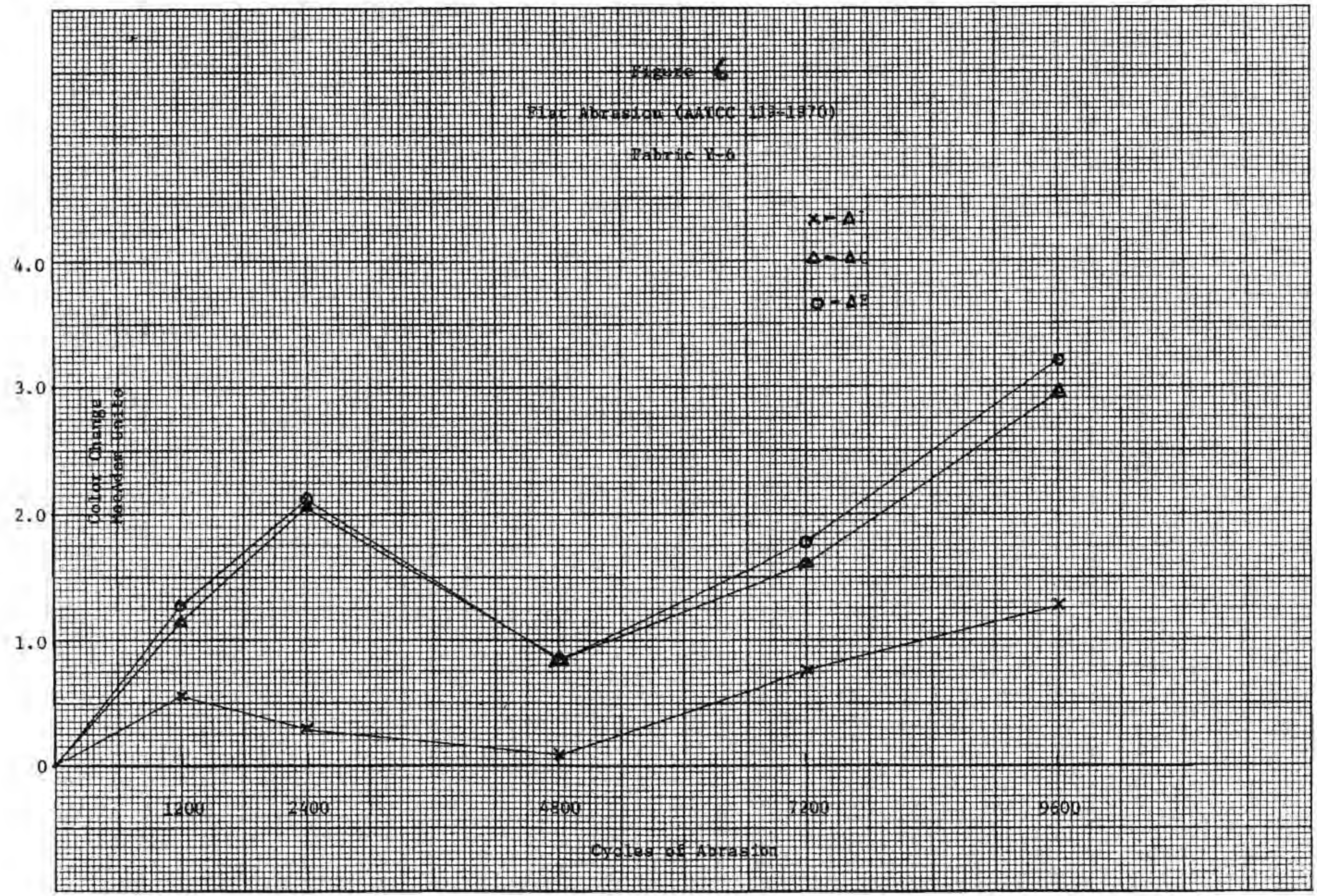


Figure 6
Flat Abrasion (AATCC 119-1970)
Fabric K-6
X – Δ
Δ – Δ
O – Δ
4.0
3.0
2.0
1.0
0
Color Change
Hunter Units
1200
2400
4800
7200
9600
Cycles of Abrasion

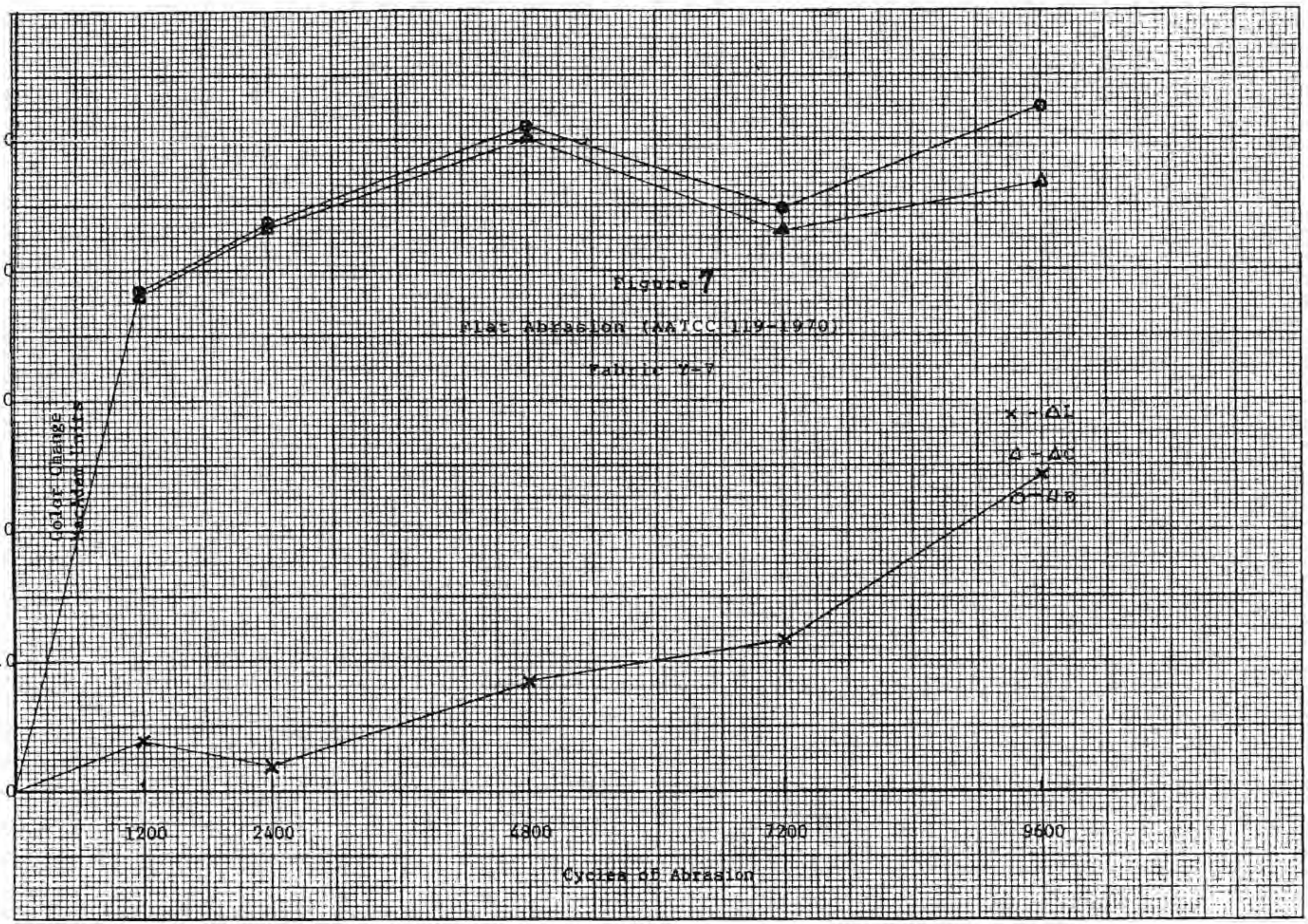


Figure 7
Flat Abrasion (AATCC 119-1970)
Fabric Y-7
x - ΔL
Δ - ΔC
O - ΔE
Color Change
MacAdam Units
5.0
4.0
3.0
2.0
1.0
0
1200
2400
4800
7200
9600
Cycles of Abrasion

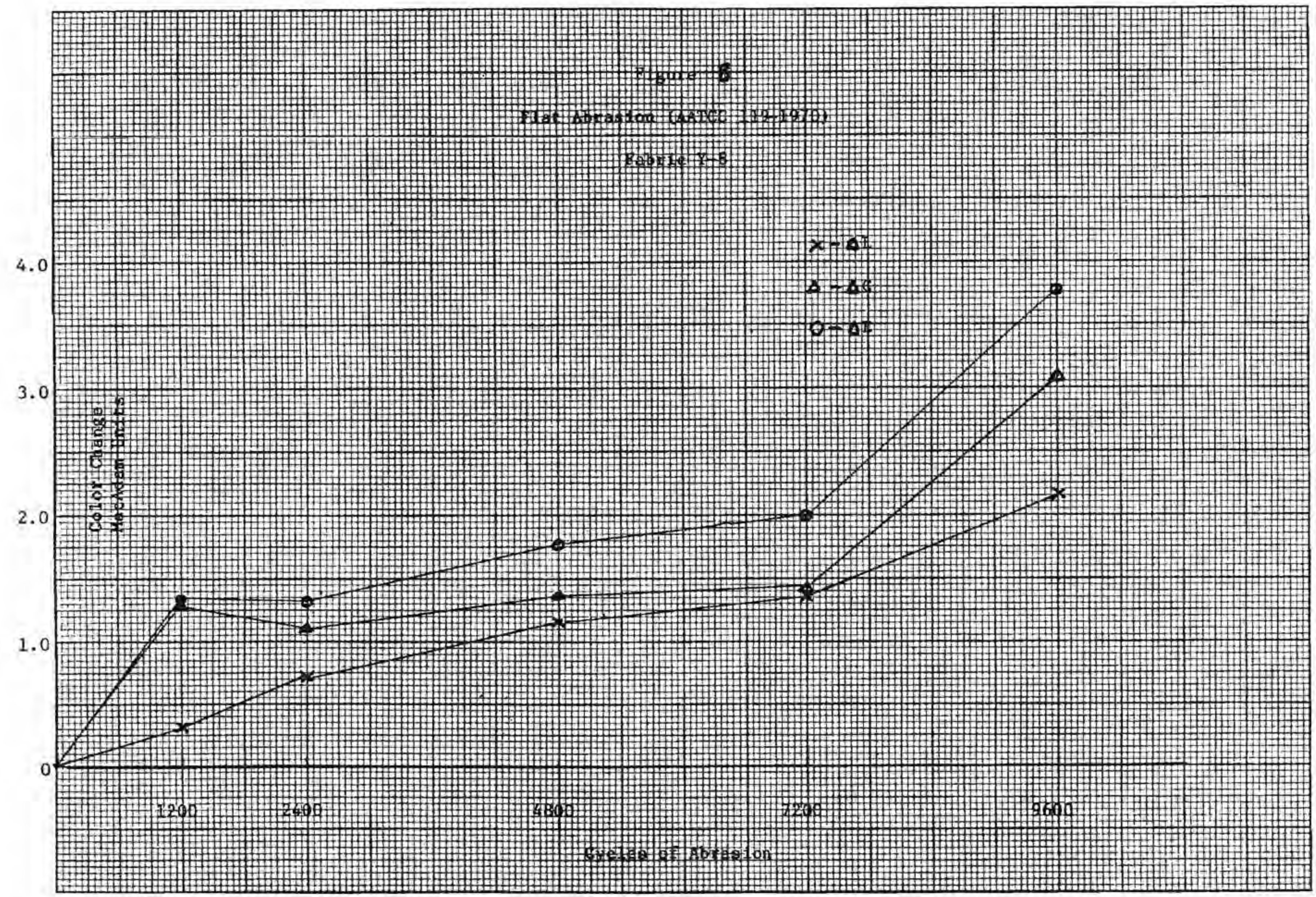


Figure 8
Flat Abrasion (AATCC 119-1970)
Fabric Y-8
X – ΔL
Δ – ΔC
O – ΔE
4.0
3.0
2.0
1.0
0
Color Change
MacAdam Units
1200
2400
4800
7200
9600
Cycles of Abrasion

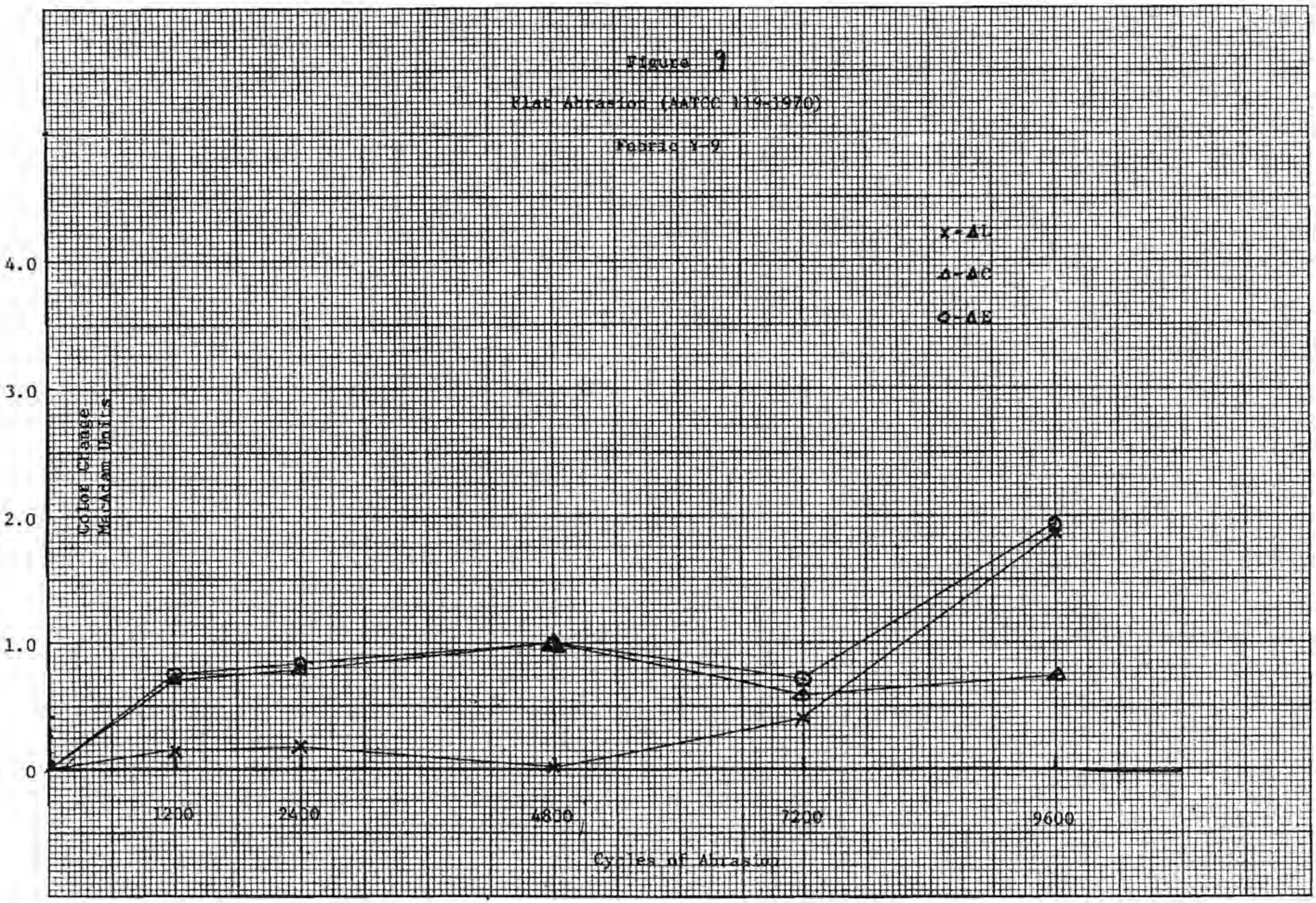


Figure 9
Flat Abrasion (AATCC 119-1970)
Fabric Y-9
X - ΔL
Δ - ΔC
O - ΔE
4.0
3.0
2.0
1.0
0
Color Change
MacAdam Units
1200
2400
4800
7200
9600
Cycles of Abrasion

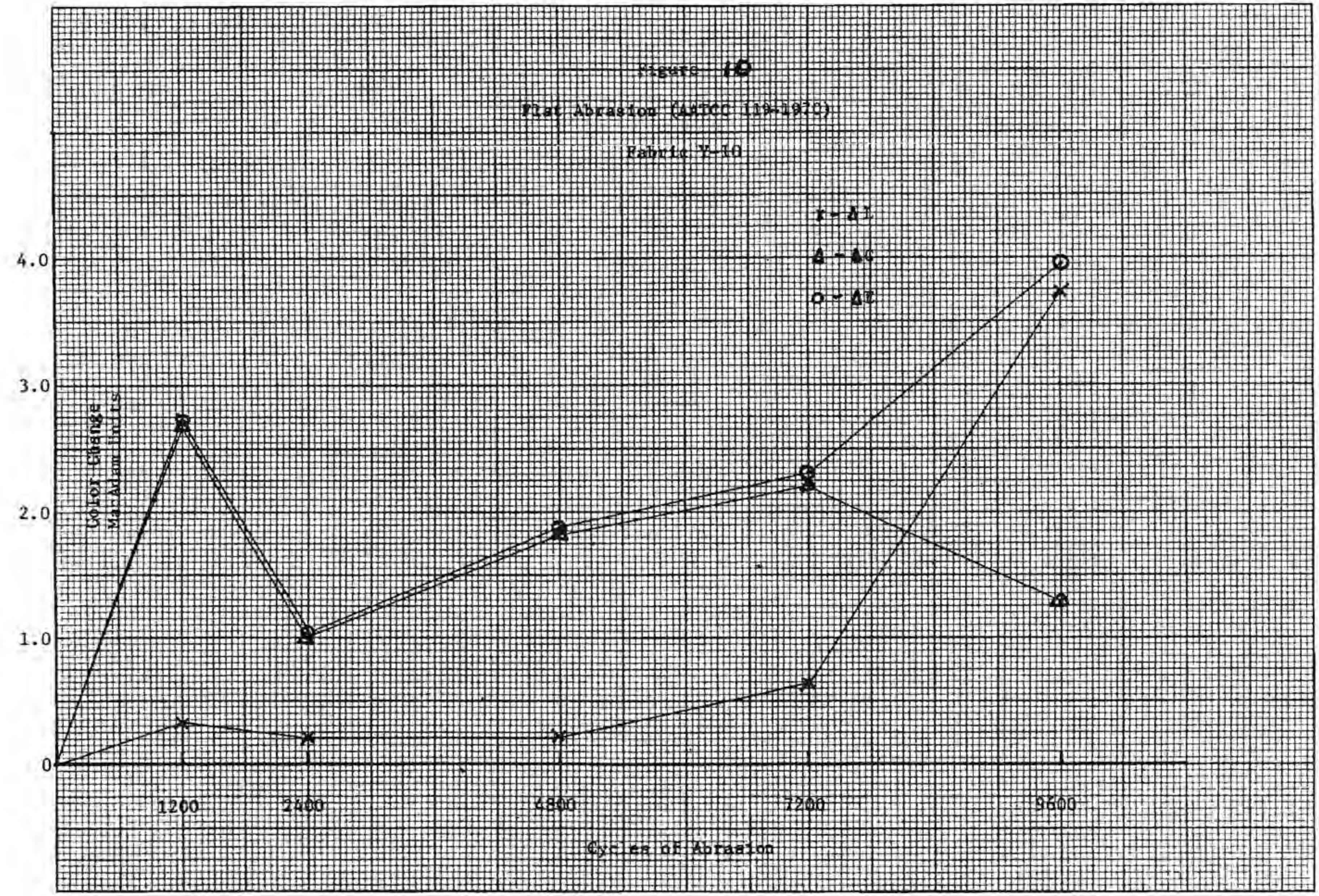


Figure 10
Flat Abrasion (AATCC 119-1970)
Fabric Y-10
x - ΔL
Δ - ΔC
o - ΔE
Color Change
MacAdam Units
4.0
3.0
2.0
1.0
0
1200
2400
4800
7200
9600
Cycles of Abrasion

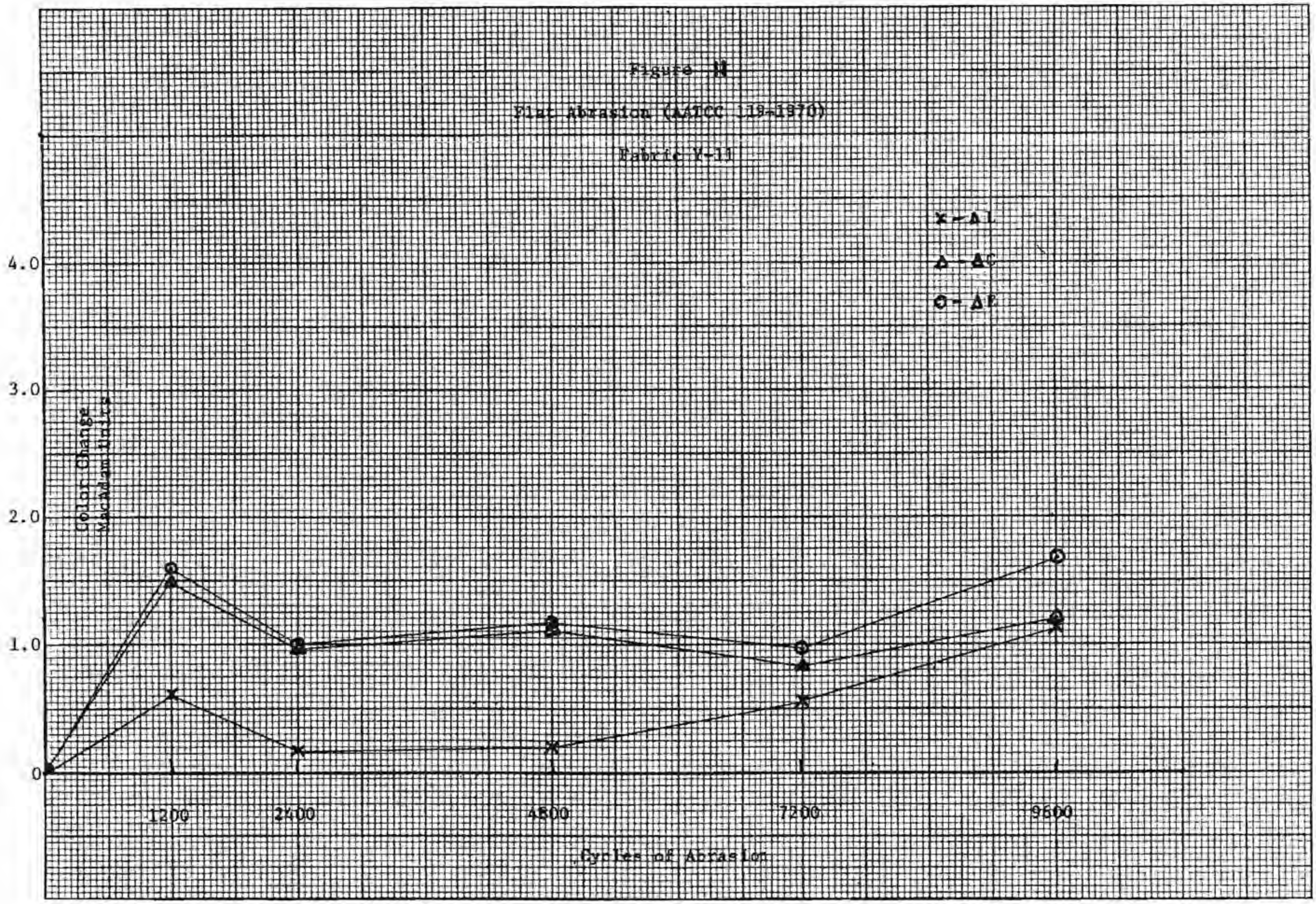
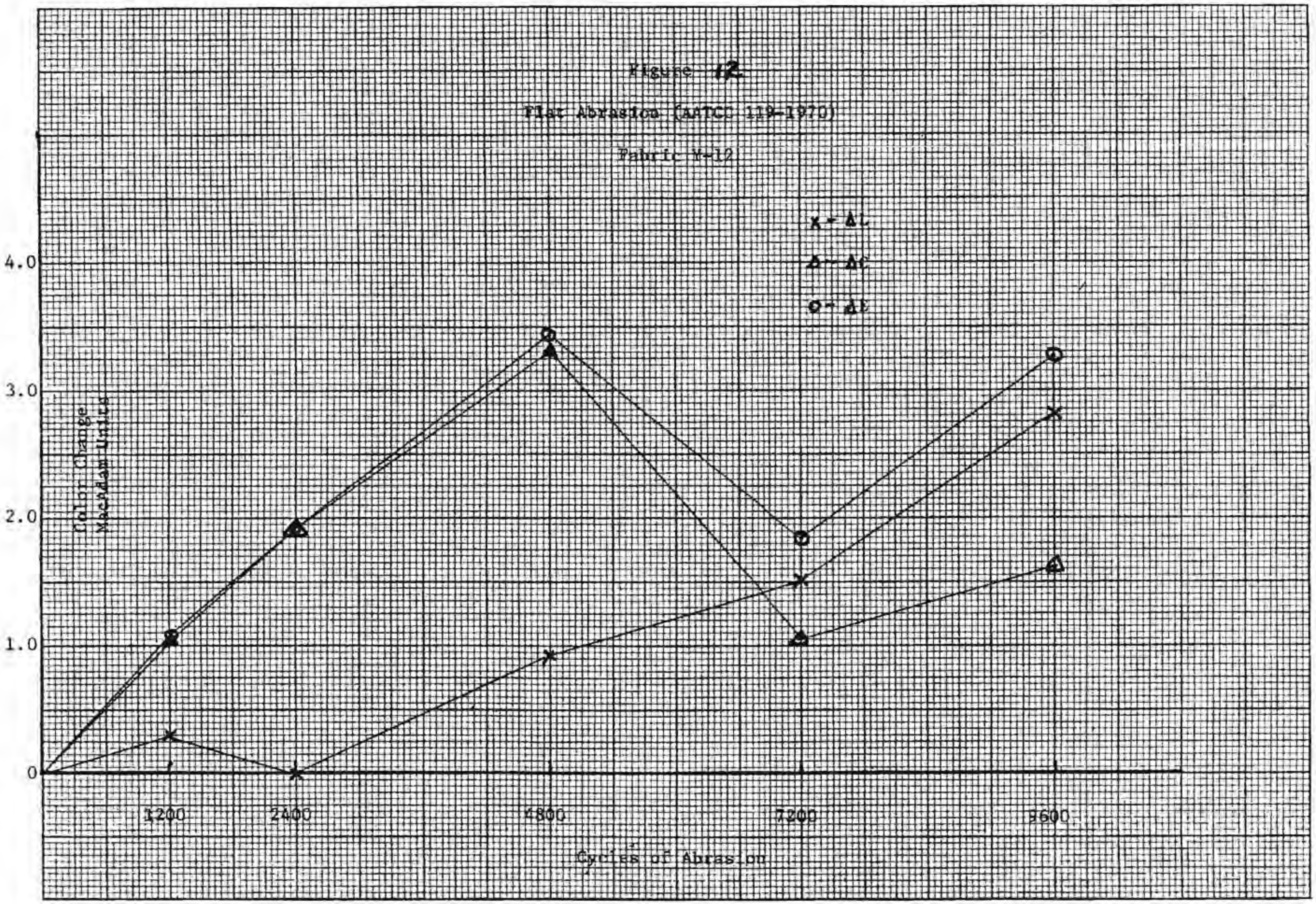


Figure 11
Flat Abrasion (AATCC 119-1970)
Fabric Y-11
X - ΔL
Δ - ΔC
O - ΔE
Color Change
MacAdam Units
4.0
3.0
2.0
1.0
0
1200
2400
4800
7200
9600
Cycles of Abrasion

K+E 10 X 10 TO 1/2 INCH 46 1320
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.



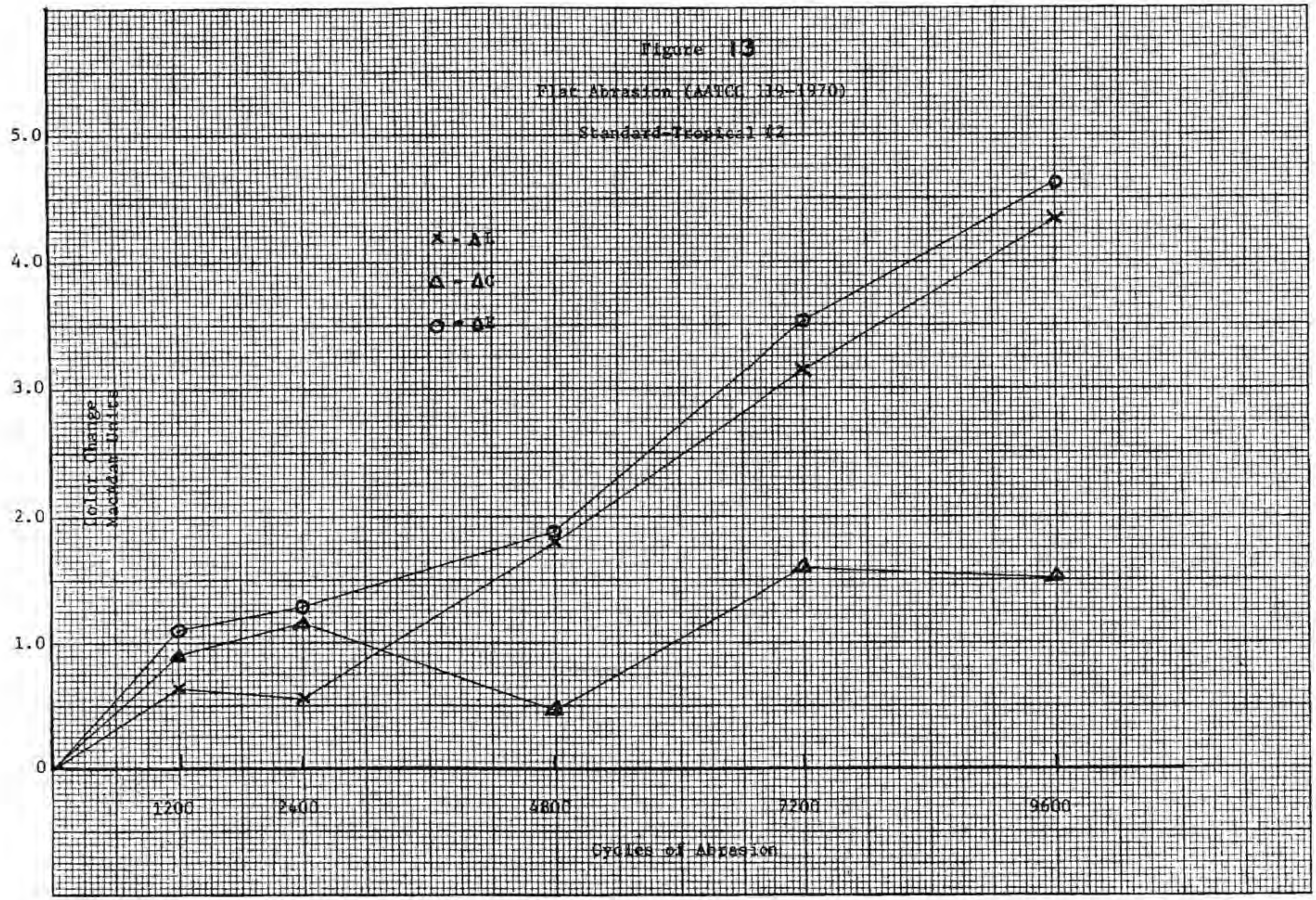


Figure 13
Flat Abrasion (AATCC 119-1970)
Standard-Tropical #2
X - ΔL
Δ - ΔC
O - ΔE
Color Change
MacAdam Units
5.0
4.0
3.0
2.0
1.0
0
1200
2400
4800
7200
9600
Cycles of Abrasion

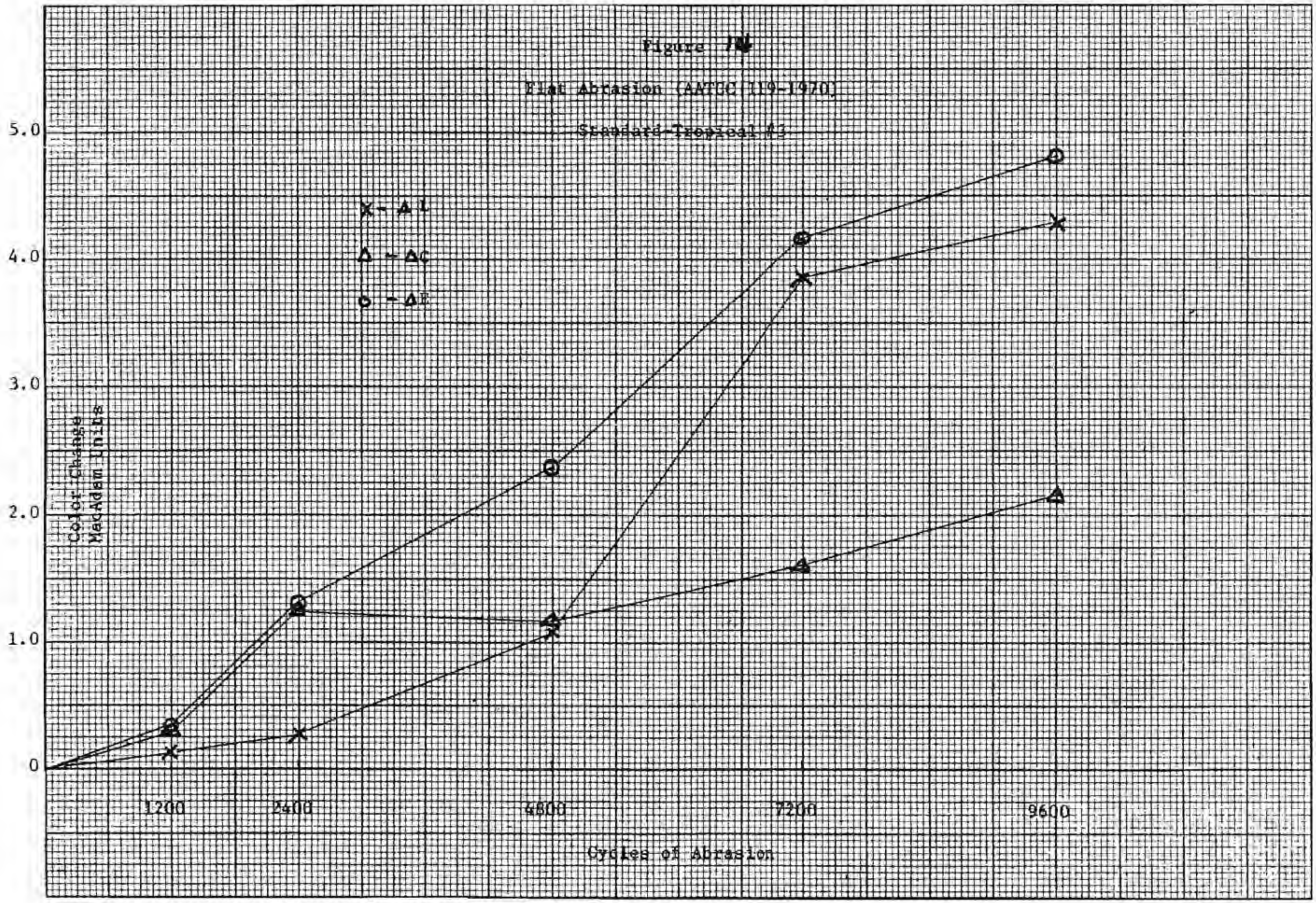


Figure
Flat Abrasion (AATCC 119-1970)
Standard-Tropical #3
X - ΔL
Δ - ΔC
O - ΔE
Color Change
MacAdam Units
5.0
4.0
3.0
2.0
1.0
0
1200
2400
4800
7200
9600
Cycles of Abrasion

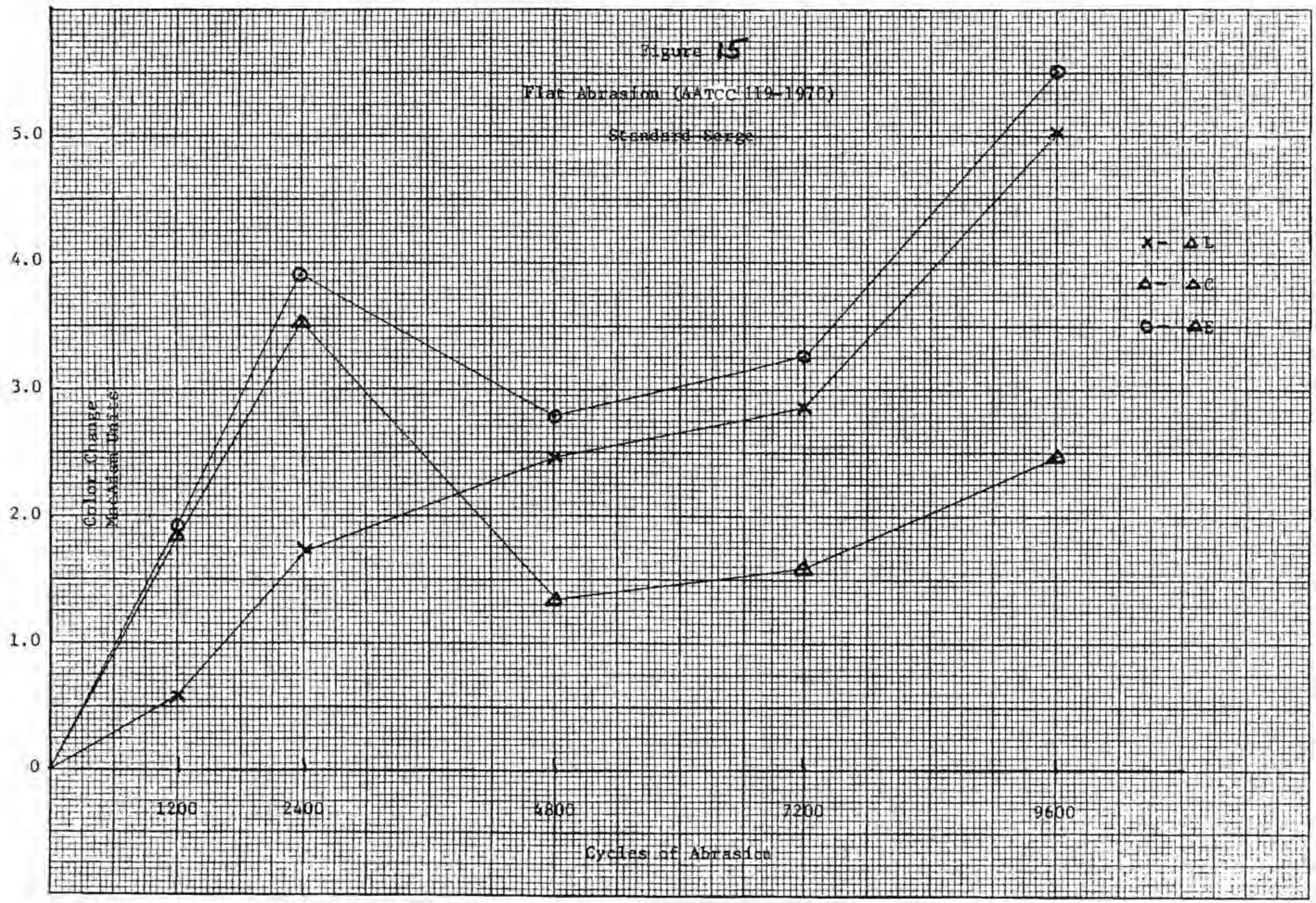


Figure 15
Flat Abrasion (AATCC 119-1970)
Standard Serge
X — ΔL
Δ — ΔC
O — ΔE
Color Change
MacAdam Units
5.0
4.0
3.0
2.0
1.0
0
1200
2400
4800
7200
9600
Cycles of Abrasion

bonizing, wool grade, and yarn twist, were not found to be important factors in frosting relative to the ones described above. It should be pointed out that the two grades of wool used do not differ much in fineness and the yarn twists used were not greatly different, 12 and 15 t.p.i.

At the time this project was started the question arose as to contribution of repeated dry cleaning on frosting. The two types of solvents used in dry cleaning are Stoddard solvent (a hydrocarbon) and perchloroethylene. It was not expected that Stoddard solvent would cause deterioration in abrasion resistance of polyester fiber; however, since perchloroethylene is known to be sorbed by polyester fibers, it was concluded that its use in dry-cleaning could be a contributing factor in abrasion resistance, particularly frosting behavior. Therefore, selected fabrics from the group of experimental fabrics were subjected to 10,20, and 30 dry-cleanings by both the Stoddard and perchloroethylene procedures. Flat abrasion tests made on the dry-cleaned fabrics did not indicate that dry-cleaning adversely affected their abrasion behavior.

10. Fabric Shrinkage

According to MIL-C-21115G, uniform fabrics must exhibit a shrinkage of no more than 2.5% in the warp direction and 2.0% in the filling direction.

The results obtained for the experimental fabrics are given in Table XXV.

Thus, all of the experimental fabrics meet the military specifications.

C. Color Fastness

Color Fastness to wet dry cleaning- Federal Test Method Standard 191-5622

Color Fastness to crocking - Federal Test Method Standard 191-5651

Color Fastness to light - Federal Test Method Standard 191-5660

Color Fastness to perspiration- Federal Test Method Standard 191-5680

TABLE XXV

Test Method:

FABRIC SHRINKAGE (%)

Polyester	Wool	40/60 Polyester/Wool Sample No.	Results W*	Results F*	60/40 Polyester/Wool Sample No.	Results W*	Results F*	Sample No.	Results W*	Results F*
Dacron Type 64 3.0 d.p.f.	64s	5-15	1.3	1.5	1-12C	0.5	0.0			
	64s-70s	3-15C	1.6	1.1	7-12	0.8	0.2			
Dacron Type 54 3.0 d.p.f.	64s	2-12C	1.1	0.9	6-15	0.9	0.5	9-12	1.0	0.5
	64s-70s	8-12	1.1	0.9	4-15C	0.8	0.3	10-18	1.7	1.2
Dacron Type 54, 4.5 d.p.f./64s wool					11-15	0.9	0.6			
Dacron Type 35, 3.0 d.p.f./64s wool					12-15	0.9	0.2			
Air Force Tropical Standard No. 1										
Air Force Tropical Standard No. 2										
Air Force Gabardine Standard										
Air Force Serge Standard										

* W WARP DIRECTION
F FILLING DIRECTION

The experimental fabrics were subjected to color fastness tests listed above. With the exception of light fastness, all of the fabrics were found to be excellent. The light fastness results were marginal with respect to meeting specifications. It was later discovered that the black panel temperature of the Fade-Ometer used was too high, higher than that specified in the standard method. This accounts for the results obtained. These light fastness tests are being repeated.

V. Statistical Analysis of Experimental Data

In most of the testing of the experimental fabrics, the standard method calls for more than one measurement to be made. The most common number of measurements was five (5). Therefore, it was possible to analyze the data statistically using a Hewlett- Packard program available for a two-way analysis of variance with replicates. In this program, two variables are considered at a time. For these two variables, the program compares the mean values for the two variables and their interaction. Since the experimental design included 5 variables, there are ten (10) possible pairs of variables that must be considered in the analysis. An F table was used to interpret the significance (confidence limits) for the variables studied.

The results of the statistical analysis are shown in Table XXVI.

The results are in substantial agreement with the conclusions previously noted above and arrived at from an inspection of the mean values.

VI. Conclusions

The experimental fabric program was designed to determine those factors in the composition, structure, and processing of wool/polyester uniform fabrics which contribute to their appearance and durability. From the results of this work the following conclusions can be drawn:

1. The superiority in resistance to frosting of Dacron type 54

Table XXVI Summary of Statistical Analysis of Fabric Properties

Test	Variables* b	d	w	c	t	Comments on Levels of Significance**
Air Permeability	.99	.99	.95			1. 60/40 PET/Wool > 40/60 PET/Wool 2. Dacron 54 > Dacron 64 3. Wool 64-70's > Wool 64's
Bending Length						
Filling	.95	.99		.95		1. 40/60 PET/Wool > 60/40 PET/Wool 2. Dacron 54 > Dacron 64 3. Carbonizing > Not Carbonized
Warp				.99		1. Carbonizing > Not Carbonized
Breaking Strength						
Grab--Filling	.99	.99				1. 60/40 PET/Wool > 40/60 PET/Wool 2. Dacron 54 > Dacron 64
Grab--Warp	.99	.99				1. 60/40 PET/Wool > 40/60 PET/Wool 2. Dacron 54 > Dacron 64
Ravel--Filling	.99	.99				1. 60/40 PET/Wool > 40/60 PET/Wool 2. Dacron 54 > Dacron 64
Ravel--Warp	.99	.99				1. 60/40 PET/Wool > 40/60 PET/Wool 2. Dacron 54 > Dacron 64

*b--Blend level
d--Type polyester
w—Grade of wool
c—Carbonizing
t--Yarn twist

**These comments relate to the variables studied.
The symbol > signifies "preferred to".

Table XXVI Continued

Test	Variables b	d	w	c	t	Comments on Levels of Significance
Random Pilling						
Singed--30 Min.	-	-	-	-	-	
Singed—60 Min.	-	-	-	-	-	
Not Singed--30 Min.	.95	.95				1. Dacron 64 > Dacron 54 2. 40/60 PET/Wool > 60/40 PET/Wool
Not Singed--60 Min.	.95	.95				1. Dacron 64 > Dacron 54 2. 40/60 PET/Wool > 60/40 PET/Wool
Flat Abrasion						
Grey Scale Rating						
1200 Cycles	-	-	-	-	-	
2400 Cycles	.99	.95				1. 60/40 PET/Wool > 40/60 PET/Wool 2. Dacron 54 > Dacron 64
4800 Cycles		.99				1. Dacron 54 > Dacron 64
7200 Cycles		.99				1. Dacron 54 > Dacron 64
9600 Cycles		.99			.90	1. Dacron 54 > Dacron 64 2. 15 tpi > 12 tpi

Table XXVI Continued

Test	b	d	w	c	t	Comments on Levels of Significance
Flat Abrasion						
Color Difference ΔE						
1200 Cycles		.99				1. Dacron 54 > Dacron 64
2400 Cycles	.95					1. 60/40 PET/Wool > 40/60 PET/Wool
4800 Cycles		.99				1. Dacron 54 > Dacron 64
7200 Cycles		.99		.95		1. Dacron 54 > Dacron 64 2. Not Carbonized > Carbonizing
9600 Cycles				.99	.99	1. Not Carbonized > Carbonizing 2. 15 tpi > 12 tpi
Hue Difference ΔC						
1200 Cycles		.99				1. Dacron 54 > Dacron 64
2400 Cycles	.95					1. 60/40 PET/Wool > 40/60 PET/Wool
4800 Cycles				.99	.95	1. Not Carbonized > Carbonizing 2. 15 tpi > 12 tpi
7200 Cycles		.95	.95	.99		1. 60/40 PET/Wool > 40/60 PET/Wool 2. Wool 64-70's > Wool 64's 3. Not Carbonized > Carbonizing
9600 Cycles		.99				1. Dacron 54 > Dacron 64

Table XXVI Continued

Test	b	d	w	c	t	Comments on Levels of Significance
Flat Abrasion						
Lightness Difference ΔL						
1200 Cycles	.99				.99	1. 60/40 PET/Wool > 40/60 PET/Wool 2. 15 tpi > 12 tpi
2400 Cycles	.99				.99	1. 60/40 PET/Wool > 40/60 PET/Wool 2. 15 tpi > 12 tpi
4800 Cycles	.95	.99	.95		.99	1. 60/40 PET/Wool > 40/60 PET/Wool 2. Dacron 54 > Dacron 64 3. Wool 64-70's > Wool 64's 4. 15 tpi > 12tpi
7200 Cycles	.99	.99	.99			1. 60/40 PET/Wool > 40/60 PET/Wool 2. Dacron 54 > Dacron 64 3. Wool 64-70's > Wool 64's
9600 Cycles	.99	.99	.95		.99	1. 60/40 PET/Wool > 40/60 PET/Wool 2. Dacron 54 > Dacron 64 3. Wool 64-70's > Wool 64's 4. 15 tpi > 12 tpi

compared to both Dacron type 64 and Dacron type 35.

2. The small improvement in resistance to frosting obtained by using a 4.5 denier Dacron type 54 rather than a 3.0 denier Dacron type 54.
3. The small improvement in resistance to frosting by increasing the yarn twist in the singles and plied yarns from 12 t.p.i. to 15 t.p.i., particularly for long times of abrasion.
4. The necessity for singeing to obtain good pilling resistance even with pilling-resistant fibers such as Dacron types 35 and 64.
5. The slightly better resistance to frosting afforded by a 60/40 polyester/wool blend fabric compared with a 40/60 polyester/wool blend fabric.
6. In order to obtain a minimum color change on abrasion, the polyester component should be slightly darker in shade than the wool component.

VII Report on Technical Conference

As a part of this program, a Technical Conference was held at the Georgia Institute of Technology 30 April, 1974 to provide a comprehensive discussion of the program to develop polyester/wool uniform fabrics with improved durability and appearance. A copy of the report of this conference is appended.

VIII. Recommendations for Production- Run Fabrics

Based on the results of the work presented at the technical conference, its critique by experts in the manufacture and utilization of polyester/wool worsted fabrics, and the subsequent statistical analysis of the data presented, the following production-run fabrics are recommended:

Item No.	Composition Polyester/Wool	Type Polyester	Type Wool	Remarks (56" width)
1.	55/45	Dacron 54 (4.5 dpf)	64s	9 oz. tropical (Type III, Class I)
2.	55/45	Dacron 54 (3.0 dpf)	64s	9 oz. tropical (Type III, Class I)
3.	55/45	Dacron 64 (3.0 dpf)	64s	9 oz. tropical (Type III, Class I)

Item No.	Composition Polyester/Wool	Type Polyester	Type Wool	Remarks (56" width)
4.	55/45	Dacron 54 (4,5 dpf)	64s	10 oz. tropical (Type III, Class 3)
5.	55/45	Dacron 54 (3,0 dpf)	64s	10 oz. tropical (Type III, Class 3)
6.	55/45	Dacron 64 (3,0 dpf)	64s	10 oz. tropical (Type III, Class 3)

Additional comments on production run fabrics:

1. The first three fabrics, items 1,2, and 3 are recommended to demonstrate the superiority of Dacron type 54 to Dacron type 64 and the improvement which is gained in replacing a 3.0 denier polyester fiber with a 4.5 denier fiber.

2. The last three fabrics, items 4,5, and 6 are duplicates of items 1,2, and 3except for difference in yarn count and ends and pick count required to meet the specifications of the 10 oz. tropical fabric (Type III, Class 3). These three fabrics are included because of statements made by the representatives of the Clothing Branch, Aeronautical Systems Division, with respect to the replacement of the 9 oz tropical fabric by the 10 oz tropical fabric.

3. All six fabrics will have the same yarn construction as specified in MIL-C-21115G. The yarn twist in both singles and ply will be 15 t.p.i.

Appendix 1

Report of Technical Conference

Polyester / Wool Uniform Fabrics With Improved Durability and Appearance

As a part of the work being done at the Georgia Institute of Technology under Contract No. F33615-72-C-1822, a technical conference was held April 30, 1974 to provide a comprehensive discussion of the program to develop polyester/wool uniform fabrics with improved durability and appearance. The conference was held at the School of Textile Engineering, Georgia Institute of Technology. Those attending included representatives of polyester fiber producer interests, wool interests, textile producer interests, and representatives of ASD/ENCU and Natick Laboratory who have considerable expertise in the fabrication and performance of military uniforms. A list of those participating in the conference is appended.

The conference consisted of a morning session for the presentation of the Georgia Tech program and an afternoon session devoted to a critique of the program and the recommended production run fabrics. Industry assessment of the adaptability of newly developed fabrics to current production methods was also sought, including all aspects of production from the choice of raw materials, yarn and fabric construction, dyeing and finishing processes, to uniform fabrication.

The morning presentation was well received and, almost without exception, the participants were complimentary of the work which had been done. The conclusions that were drawn from the work were:

1. the superiority in resistance to frosting of Dacron type 54 compared to both Dacron type 64 and Dacron type 35.

2. the small improvement in resistance to frosting obtained by using a 4.5 denier Dacron type 54 rather than a 3.0 denier Dacron type 54.

3. the improvement in resistance to frosting by increasing the yarn twist in both the singles and plied yarns from 12 t.p.i. to 15 t.p.i.

4. the necessity for fabric singeing to obtain good pilling resistance even with pilling-resistant fibers such as Dacron types 64 and 35 and

5. the slightly better resistance to frosting afforded by a 60/40 polyester/ wool blend fabric compared with a 40/60 polyester/wool blend fabric.

These conclusions were consistent with the experience of the participants.

Dr. Andreen (duPont), was in agreement that the use of 4.5 denier Dacron type 54 was a good idea but, he pointed out that textile mills prefer to use, if possible, only one fiber type and denier which gives them flexibility in several yarns and fabrics rather than a variety of fiber types and deniers. He also pointed out that the small potential improvements in resistance to frosting afforded by the 4.5 denier fiber should be verified in wear tests.

Mr. Hildebrandt (Methuen) and Mr. Spencer (Westbrook Spinning) who have had considerable experience in processing polyester-wool blends, pointed out that the processability of the 4.5 denier polyester fiber with wool was superior to that of the 3.0 denier fiber. Mr. Guerin (Florence Dye Works) has stated, by letter, that in the top blending operation, the 4.5 denier fiber is superior to the 3.0 denier fiber. Mr. Reynolds (duPont) stated that his work has shown that this is true. He pointed out that, although the spin limits for the 4.5 denier fiber with 64s wool is about 45s worsted count yarn, there was no reason for any difficulty in making the 40's yarn required in the tropical 9.0 oz. fabric. Mr Spencer claimed that he had successfully made yarn of excellent quality having a worsted count of 48 using 4.5 denier polyester fiber. It should be noted that this count lies outside the spin limits stated by Mr. Reynolds. It would appear that, from a technical standpoint, there are two factors to be considered in the selction of a 4.5 denier in place of a 3.0 denier fiber, namely,

1. processability of the two fibers and

2. the relative merits of the two fibers from the standpoint of their resistance to frosting as determined from extensive wear tests.

Mr. Campbell (Natick) pointed out that the shade difference between the polyester and wool components is an important factor in the color change on abrasion. His recommendation is that the polyester component should be about twenty percent heavier in depth of shade than the wool component.

Mr. Reynolds was questioned privately concerning the importance of yarn twist on abrasion (frosting and pilling). He has concluded from his work that the optimum twist in both the singles and ply yarn for the tropical fabric is 13 to 14 t.p.i. We have found in our work that 15 t.p.i. was slightly better than 12 t.p.i.

The question was raised as to whether the experimental fabrics meet the government specifications on shrinkage. These specifications are 2.5 and 2.0 per cent in the warp and filling directions, respectively. At the time of the conference, these measurements had not been made. The tests have now been completed and all the fabrics fall well within the government specifications.

With respect to the finishing of the experimental fabrics, it was concluded from the description of the finishing processes used that the fabrics had been finished in a manner consistent with the finishing of all-wool worsted fabrics. The thermal treatments in finishing were not as severe as those used for fabrics which contain a substantial quantity of polyester fiber. There was no indication that such treatments are either desirable or necessary. However, for completeness in this program, selected fabrics will be thermoset to determine the effect of such treatments on fabric properties.

It was the concensus of those participants who voiced an opinion on the "hand" of the experimental fabrics that even though the fabrics made using 3.0 denier

Dacron type 54 could be easily distinguished from the fabric made using 4.5 denier Dacron type 54, both fabrics had a "hand" superior to that of the tropical standards. Although we have subsequently made drape measurements on all of the experimental fabrics (FRL Method), it is difficult to assess the effect of variables in composition and construction on the drape coefficient due to the variations in fabric weight and the variations in the number of nodes exhibited by the hanging fabrics. In any case, all of the fabrics had lower values for their drape coefficients than that for the tropical standard.

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AFML-TR-75-98

DEVELOPMENT OF POLYESTER/WOOL UNIFORM FABRIC WITH IMPROVED DURABILITY AND APPEARANCE

Georgia Institute of Technology
Atlanta, Georgia 30332

August 1975

TECHNICAL REPORT AFML-TR-75-98

Final Report for Period 15 May 1972 - 30 November 1974

Air Force Materials Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

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This technical report has been reviewed and is approved.

Donald R. May, Jr.

Donald R. May, Jr., Project Monitor

FOR THE COMMANDER

T. J. Reinhart

T. J. Reinhart, Chief
Composites and Fibrous Materials Branch
Nonmetallic Materials Division

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The mechanism of "frosting" of polyester/wool uniform fabrics has been established. An exploratory research and development program has been carried out to establish those factors in the composition, construction, and processing of polyester/wool uniform fabrics which contribute to their wearing characteristics, particularly their pilling and frosting behavior. Based on findings, six (6) specification fabrics exhibiting improved wear performance have been prepared for a service test program.

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PREFACE

This report was prepared by the School of Textile Engineering, Georgia Institute of Technology, Atlanta, Georgia under U.S. Government Contract No. F33615-72-C-1822. The work was initiated under Project 7320, "Fibrous Structural Materials," and was conducted from May 15, 1972 through November 30, 1974. It was administered under the direction of the Air Force Materials Laboratory, Air Force Systems Command, with Mr. Donald R. May, Jr., acting as project engineer.

Dr. W. Denney Freeston was the Georgia Institute of Technology director responsible for the overall program. The day to day conduct of the program including the laboratory investigations and procurement of materials and services for production of experimental and specification fabrics was the responsibility of Dr. Walter C. Carter. The laboratory studies were carried out by Mr. A. J. Maguire and Ms. Sandra K. Henson.

The authors wish to express their appreciation to Dr. B. R. Livesay who made single-filament abrasion tests in connection with the work and to those companies who provided the necessary materials and services related to production of fabrics, namely, Wellman, Incorporated, Florence Dye Works, Textile Research Services, Westbrook Spinning Company, Florence Finishing Company, Burlington Industries, and Methuen International Mills.

This report is submitted by the authors in May 1975.

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SECTION I

SUMMARY

A. Program Objectives and Scope

The objective of this work was exploratory research, development, and evaluation of polyester/wool Air Force Blue 1549 uniform fabrics having improved drape, handle, fabricability, wear, and resistance to "frosting" over current Air Force fabrics. To achieve this objective, the effects of the type polyester used, yarn and fabric constructions, and dyeing and finishing methods used on fabric properties have been investigated. The primary emphasis in the work was to determine the cause of "frosting" of polyester/wool fabrics and to discover routes to the production of fabrics which have improved abrasion properties. Based on the results obtained, the production of six (6) specification fabrics was required for the fabrication of uniforms which will undergo a three (3) year service test to be conducted by the Clothing Branch, Aeronautical Systems Division.

B. Conclusions

From a detailed examination of a worn Air Force uniform and the abrasion characteristics of a standard Air Force tropical fabric (Type III Class 1), it was concluded that the wool component of the fabric is worn away preferentially and the frosted appearance of both the worn uniform and the abraded standard fabric is due primarily to the polyester component, its fibrillation resulting in an increase in light scattering and thus an increase in the luminosity of the fabric. Therefore, in the examination of those factors in the composition, construction, and processing of uniform fabrics, the focus was primarily on the polyester component of the blend. Exploratory work in this program led to the conclusion that there are many factors which must be considered in the development of more durable uniform fabrics and the task of evaluating each of the factors would be formidable. Therefore, those factors considered to be most important in abrasion were chosen for further study. These factors included

1) type of polyester fiber
2) denier of polyester fiber
3) grade of wool
4) fabric carbonizing
5) relative amounts of wool and polyester fiber in fabric
6) yarn twist
7) fabric singeing

A statistically designed experiment including these factors was carried out. A complete evaluation of the properties of the experimental fabrics led to the following conclusions:

1) The type of polyester used in the uniform fabrics has a pronounced effect on their abrasion (frosting) properties, e.g., Dacron type 54 is superior to both Dacron type 64 and Dacron type 35.

2) There is a small improvement in resistance to frosting obtained by using a 4.5 denier polyester fiber rather than a 3.0 denier polyester fiber (Dacron type 54).

3) An increase in yarn twist from 12 t.p.i. to 15 t.p.i. results in a small improvement in resistance to frosting.

4) Singeing of uniform fabrics is required in order to obtain fabrics with good resistance to pilling.

5) A 60/40 polyester/wool fabric has slightly better resistance to frosting than a 40/60 polyester/wool fabric.

6) In order to obtain minimum color change on abrasion, the polyester component should be darker in shade than the wool component.

7) The processing of 4.5 denier Dacron type 54 with wool through dyeing, blending, and yarn spinning was found to be superior to that of 3.0 denier Dacron type 54.

8) The grade of wool (64s versus 64s-70s) has little effect on abrasion characteristics.

Based on the results obtained in the experimental fabric program, six (6) specification fabrics (approximately 500 yards of each) were prepared to demonstrate the superiority in abrasion properties of Dacron type 54 compared with Dacron type 64 and the improvement which is gained by replacing a 3.0 denier polyester fiber with a 4.5 denier polyester fiber. These fabrics have been completely evaluated. It is concluded that fabrics containing Dacron 54 are indeed superior to fabrics containing Dacron 64. Although the processing of fabrics containing 4.5 denier Dacron 54 was judged to be superior to that of fabrics containing 3.0 denier Dacron 54, the improvement in abrasion resistance expected by the replacing of 3.0 denier with 4.5 denier was not found. These six (6) fabrics will be made into uniforms for a service test program to be conducted by the Clothing Branch, Aeronautical Systems Division. The results of this program may reveal performance characteristics not apparent from laboratory evaluation results.

C. Recommendations

With respect to the durability and resistance to "frosting" of uniform fabrics, the major considerations in the composition and construction of the fabrics are the type polyester used, its size (diameter) relative to that of wool, and the amount of twist in the yarns. It is recommended that the choice of the type polyester be based on its resistance to abrasion. In this work, Dacron type 54 was found to be superior to the chemically modified Dacron type 64. It is also recommended that consideration be given to the use of a polyester fiber having a diameter approximately that of the wool with which it is blended to demonstrate the improvement in spinning performance and abrasion characteristics which would result. An increase in yarn twist over that found in the Air Force standard fabric (Type III, Class 1) has been shown to give some improvement in abrasion resistance.

With respect to processing conditions, the following recommendations are made:

1. The wool and polyester components should be dyed separately in top form
2. Carbonizing of fabrics should be avoided if feasible
3. Good singeing and shearing of fabrics is demanded for optimum resistance to pilling and frosting

SECTION II

CAUSE OF FROSTING OF POLYESTER/WOOL UNIFORM FABRICS

A. Definition of Frosting

A major shortcoming of the polyester/wool blends, Blue 1549, gabardine, tropical, and serge fabrics currently used by the Air Force in uniforms is "frosting". The fabrics have good drape and handle, excellent wear resistance, and durability. The objectionable appearance of the fabrics due to excessive "frosting" is the reason usually given for discontinuing wearing a uniform, not that it is worn out. "Frosting" is a term used to describe fabrics whose appearance is similar to early morning frost on a grass lawn. Years ago it was applied to dyed wool fabrics that contained hair fiber or damaged fiber which did not dye to the same shade as the rest of the wool. More recently, it has been used to describe the appearance of some abraded polyester/cotton, polyester/rayon, and polyester/wool fabrics as well as single fiber fabrics. According to the "Technical Manual of the American Association of Textile Chemists and Colorists" frosting is defined as

> "a change of fabric color caused by localized abrasive wear. It may be the result of differential wear, as in multi-component blends in which the fibers do not match in shade, or of the abrasion of single fiber constructions in which there is a variation in or incomplete penetration of dyestuff. Frosting is sometimes referred to as 'differential wear' or 'fibrillation'."(1)

Another characteristic of fabrics containing polyester fibers is "pilling", a physical process in the surface of a fabric taking the form of small balls made up of fibers(2). Pilling is the usual complaint with fabrics produced from low density, low twist, yarns in a low density fabric construction whereas, military uniform fabrics show little pilling due to the use of high density, high twist yarns. Several possible causes for the objectionable changes in fabric appearance due to abrasion have been suggested but there has been little assessment of their relative importance. It is not surprising that there are conflicting views since there are many uncontrolled variables both in the fiber content of the military uniform fabrics, fabric construction, and in the chemical, thermal, and mechanical treatments involved in their manufacture. Military specifications for uniform fabrics include specifications for both wool and polyester fibers to be used. For wool, 64s grade U.S. Standard (or finer) is specified. For the polyester fiber component, the only requirement is that it be made from poly (ethyleneterephthalate), either homopolymer or modified polymer, 3 denier, semi-dull. It is well known that polyester fibers derived from either the homopolymer or modified polymers can be produced which have a broad spectrum of physical properties, and thus, would be expected to possess widely different abrasion and pilling resistance. They would also be expected to respond differently to thermal, chemical and mechanical treatments required to produce fabrics meeting military specifications.

The usual explanation for frosting of polyester/wool uniform fabrics is differential wear of the two fibers, wool being preferentially worn away. Frosting is attributed to fibrillation of wool, poor dye penetration of both fibers, and the difference in color between the two fibers (3) Less frosting is evident on fabrics made from top dyed fibers than those which are piece dyed provided the dye penetrates the fibers sufficiently. Pilling is associated with the stronger polyester fiber. Polyester fiber manufacturers describe the pilling resistance of their fibers and the effects of fabric and yarn construction on pilling tendency; however, there is little information with respect to their abrasion resistance, particularly when the fibers are present in fabric constructions which have little tendency to pill such as that characteristic of military uniform fabrics.

It was concluded from other published literature that the primary emphasis has been on pilling rather than on frosting of blend fabrics(2-16). It is not surprising that a comprehensive understanding of the mechanism of frosting is needed.

Although speculations can be made as to what would be the effect of various parameters in the composition, construction of polyester/wool fabrics and processing conditions, including dyeing and finishing on their abrasion behavior, it was mandatory that a clear understanding of the abrasion behavior of the current uniform fabrics be first established. Initial work in this program was directed toward this goal and consisted of a comprehensive study of a worn Air Force uniform which exhibited frosted areas due to abrasion. In addition, specification Air Force tropical fabrics were abraded using a standard laboratory abrasion test procedure (1). The results of the study of the worn fabric and the laboratory abraded fabrics are described below.

B. Examination of Worn Uniform

A worn Air Force uniform has been studied to gain an understanding of the frosting problem. The entire uniform was not available, only a sleeve of the uniform being supplied by the Air Force Materials Laboratory. The uniform had been worn 110 times and dry-cleaned 44 times. Badly frosted and unfrosted areas of the fabric were examined optically at low power (~40x) and at high magnifications (up to 500x) using the scanning electron microscope.

At low magnification, it was apparent that many fibers had been abraded away leaving fiber ends which had a crystalline appearance, free of dye. At higher magnification, the broken ends of the damaged polyester fibers were shown to be highly fibrillated whereas those of wool were blunt with little fibrillation. The cuticle was missing from some damaged wool fibers. It was clear that the wool fibers were more completely abraded away than the polyester fibers. In order to establish which of the two fibers was responsible for the frosted appearance, the wool component was removed by treating samples of the frosted and unfrosted fabrics with an aqueous 5.25 percent solution of sodium hypochlorite (5.00 percent "available chlorine"). The removal of wool was found to be quantitative with no apparent damage to the polyester fiber and with no effect on the dye in the polyester fiber.

The fabrics resulting from this treatment were similarly examined by optical and scanning electron microscopy.

A comparison of the frosted and unfrosted fabrics, before and after removal of wool, lead to the following conclusions:

1. There is differential wear of the two fibers, wool being more easily damaged.
2. The polyester component is damaged, leading to fiber ends which are highly fibrillated.
3. The frosted appearance of the worn area is unchanged by the removal of wool showing conclusively that the polyester fiber is responsible for the frosted appearance
4. Since both the polyester and wool fibers were found microscopically to be well penetrated by dye and dyed to an approximately solid (i.e. equivalent) shade, the frosted appearance is attributed to high light scattering by the polyester fibrils leading to an increase in the luminosity of the fabric.

C. Abrasion Behavior of Air Force Blue 1549 Tropical Fabric

A study was made of the resistance to flat-abrasion of the Air Force Blue 1549 tropical standard fabric to determine whether the frosting produced has the same character as that found in the worn uniform. In addition, it was desirable to know the severity of testing that would be used in studying the effect of various modified fabric constructions, fiber processing procedures, and wet processing procedures on the abrasion resistance of the uniform fabric in order to produce an improved fabric.

The flat-abrasion test used is that described in the Technical Manual of the American Association of Textile Chemists and Colorists, Test Method 119-1970 (1). This test calls for the Stoll Universal Wear Tester, Model CS-22C with a frosting attachment. The abrading surface is a stainless steel wire screen. A single test by this method consists of 1200 abrasion cycles. The Blue 1549 standard fabric was subjected to 14,400 cycles of abrasion in 1200 cycle increments. Each abraded sample was examined microscopically (40x) and the change in color estimated by comparison with a standard geometric grey scale as specified in the test and by quantitative color measurements using the IDL Color Eye. The fabrics were then washed in Stoddard solvent and color measurements made. Following this, the wool component was removed with aqueous sodium hypochlorite. After the fabrics had been conditioned, their color was again determined.

The measured color of each abraded sample was compared with that of a control unabraded sample. The color differences are expressed in terms of MacAdam color difference units: ΔE, total color difference, ΔL difference in lightness, and ΔC, chromaticity difference. The results are shown in Figures 1 through 4. The change in ΔE and ΔL with increasing abrasion is in good agreement with the changes noted visually and correlate well with the ratings for the degree of frosting expressed in terms of a standard geometric grey scale of color difference. Up to 3600 cycles, the frosting is negligble, corresponding to a 4 to 5 rating on the geometric grey scale. The small measured color changes is probably due to the initial chromaticity change resulting from the preferential damage and removal of surface wool fibers. Frosting is barely perceptible at 4800 cycles. At 7200 cycles, the polyester fibers become severely damaged but not broken away from the fabric. Further abrasion, up to 12,000 cycles, leads to a breaking away and removal of the damaged fibers with little change in frosting. At 13,200 cycles there is again a larger increase in frosting. It would appear from Figure 1 that the frosting occurs in stages. This is less apparent after washing with Stoddard solvent. A comparison of Figures 2 and 3 clearly shows that the polyester fiber is primarily responsible for the color change. Both the trends and magnitudes of ΔE and ΔL values are the same for the blend fabric and the fabric containing polyester fiber alone.

The results of this work indicated that in order to improve the durability of the uniform fabric, the most durable polyester fiber should be used. In addition, those dyeing and finishing conditions must be chosen which result in:

1. Solidity of shade (union-shade)
2. Good fiber penetration by dye
3. Minimum damage to both wool and polyester

From examination of the worn Air Force uniform and flat abraded standard Air Force fabric, it was concluded that the wool is worn away preferentially and the frosted appearance is due primarily to the polyester component. In this work, the wet processing conditions used in making the fabrics were unknown. Therefore, to provide more positive evidence, an unscoured, undyed Dacron 54/wool fabric was abraded prior to dyeing. In this way, the effect of wet processing on abrasion was eliminated. The fabric was abraded for 3600 cycles using the Stoll Universal Wear Tester. One of the abraded fabrics was dyed, with a disperse dye, Latyl Blue LS (duPont). Under the dyeing conditions used, the polyester component was well-dyed and the wool component was only slightly stained. A second abraded fabric was dyed with a chrome dye, Acid Chrome Blue RRA. Only the wool component dyed. The abraded area of the fabric dyed with the disperse dye was darker than that of the unabraded area, whereas, the reverse was found for the fabric dyed with the chrome dye. These results are consistent with the previous conclusion that wool is preferentially worn away.

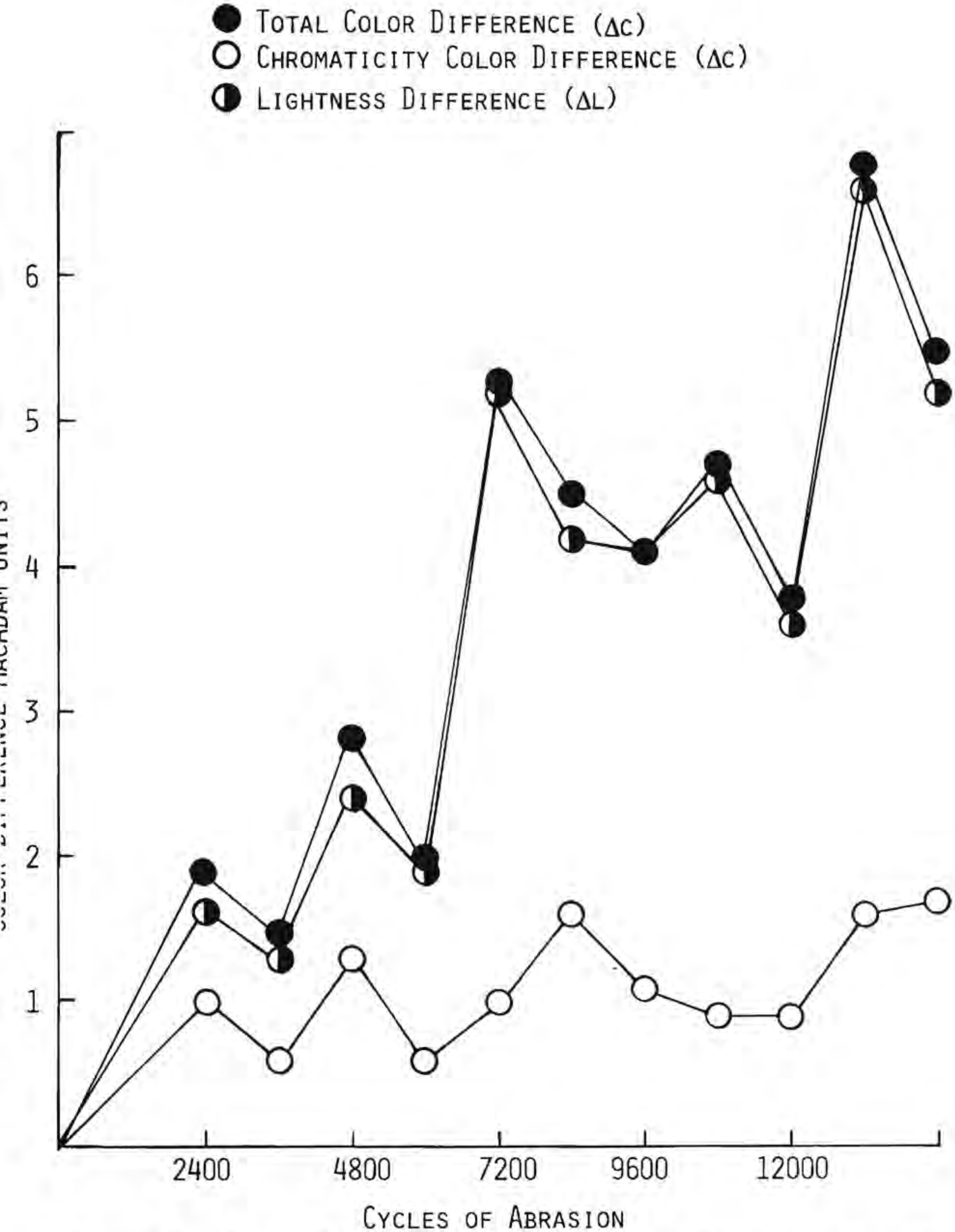

FIGURE 1. COLOR CHANGE OF AIR FORCE BLUE 1549 FABRIC DUE TO FLAT ABRASION

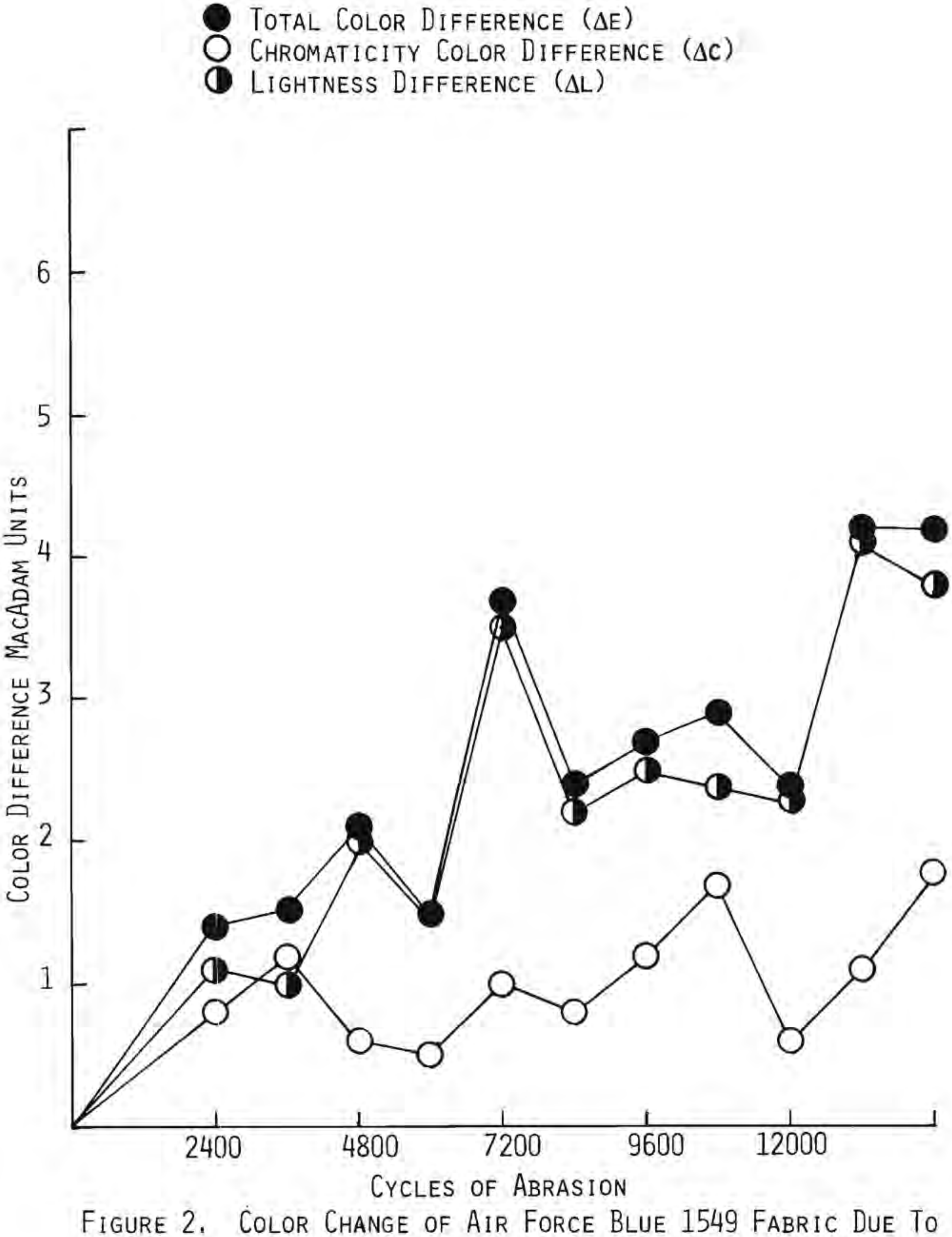

Figure 2. Color Change of Air Force Blue 1549 Fabric Due To Flat Abrasion After Washing Abraded Samples With Stoddard Solvent

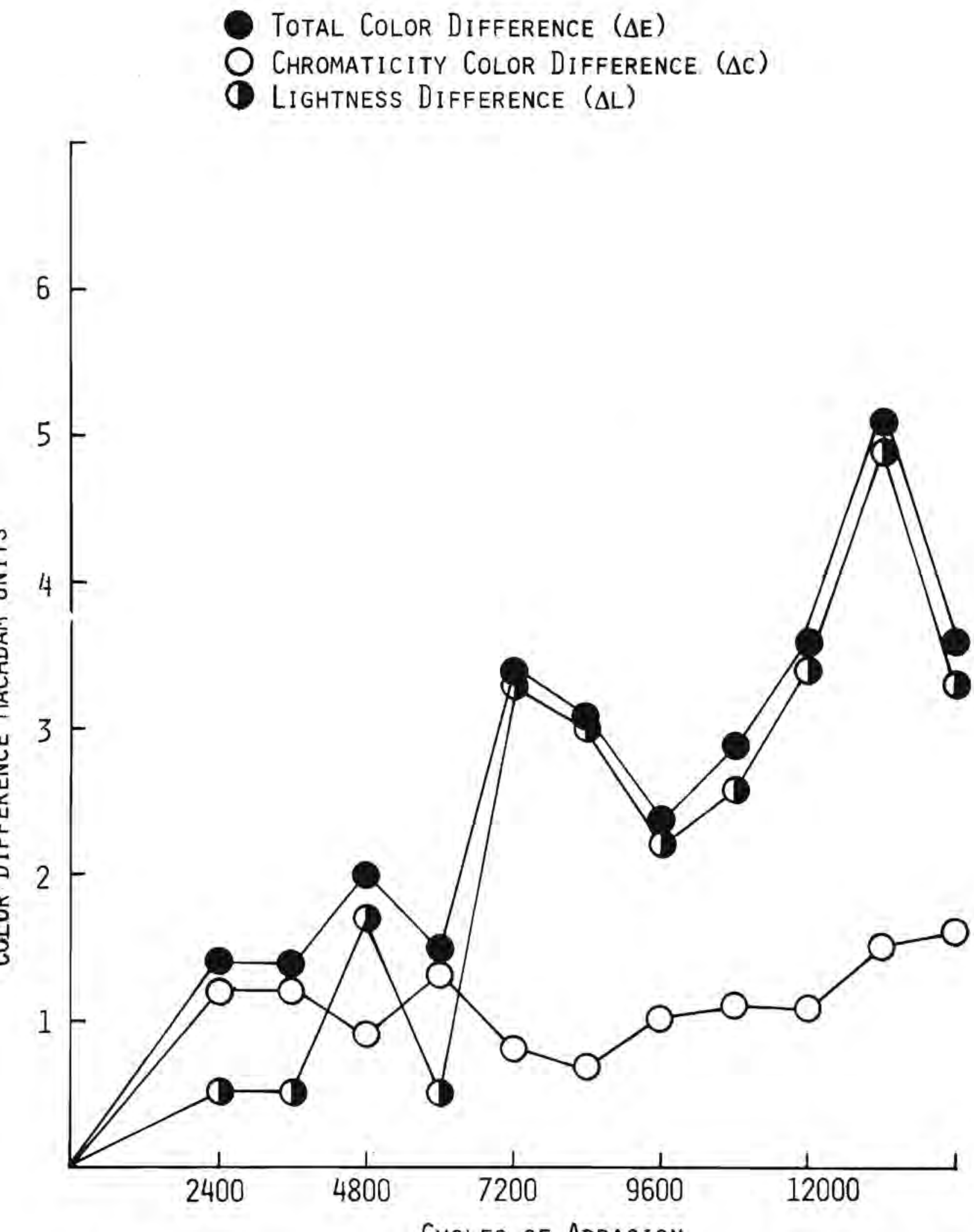

FIGURE 3. COLOR CHANGE OF AIR FORCE BLUE 1549 FABRIC DUE TO FLAT ABRASION AFTER WASHING WITH STODDARD SOLVENT AND REMOVAL OF WOOL COMPONENT OF BLEND

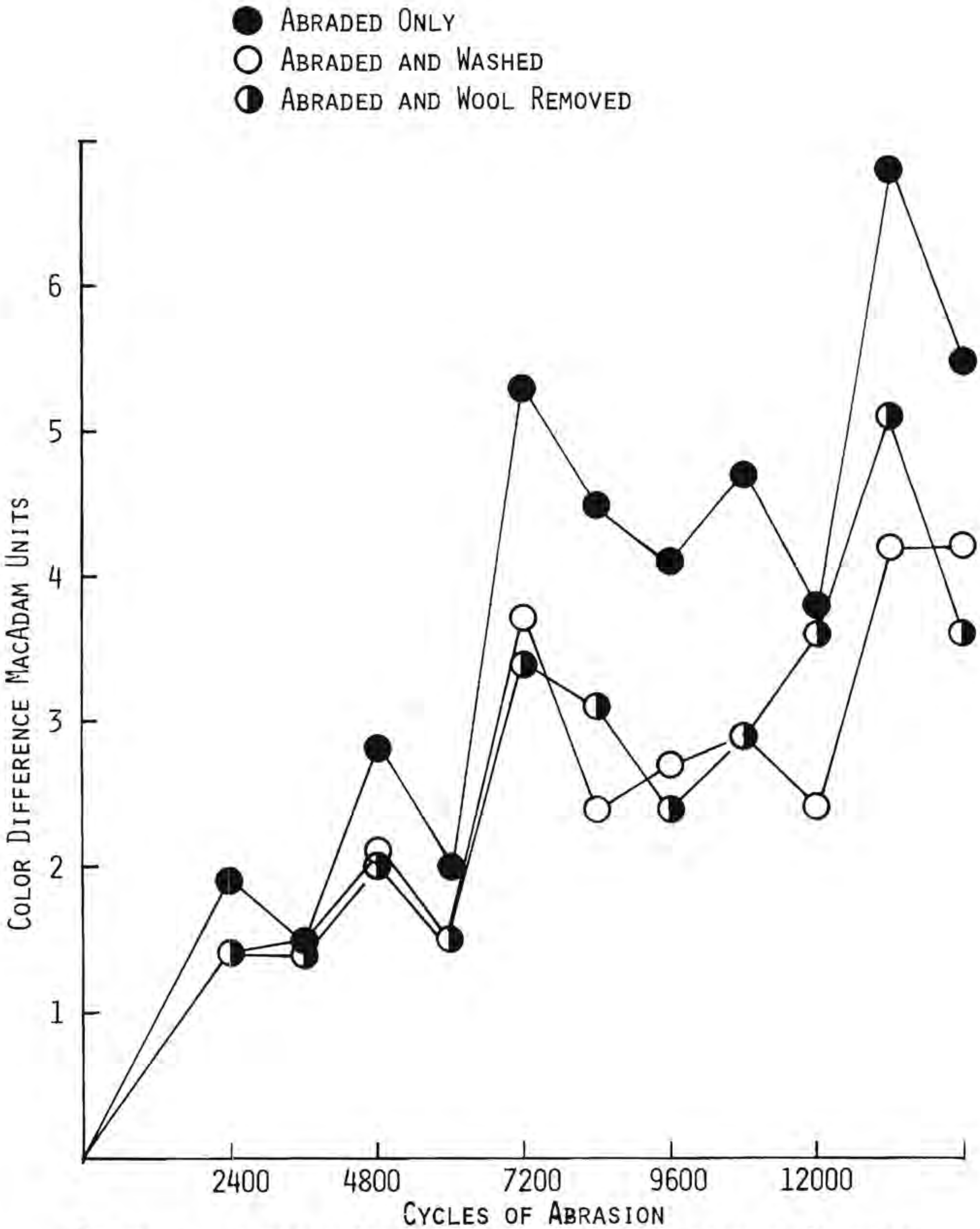

FIGURE 4. AVERAGE COLOR CHANGE (ΔE) FOR ADBRADED STANDARD EFFECT OF WASHING WITH STODDARD SOLVENT AND REMOVAL OF WOOL.

D. Analysis of Standard Air Force Blue 1549 Fabric (Tropical)

1. Description of Standard Fabric No. 1

cloth, tropical
Burlington
8305-926-6659
DSA-100-69-C-1477
Lot 8
Roll 6110

2. Fiber Content Analysis

Average polyester content	58%
Average wool content	42%

These values are based on the weight of the fabric conditioned at 70°F, 65% relative humidity.

3. Fabric Construction

Average warp ends/inch 54
Average filling ends/inch 45
Average weight (oz./sq.yd conditioned) 5.79

4. Yarn Construction

Filling Yarn

Ply yarn
Twist 10.7 t.p.i.
Contraction, 1.3%
Yarn number (Worsted System) 20s

Singles yarn
Twist 10.9 t.p.i.
Yarn Number (Worsted System) 40.3s

Warp yarn

Ply yarn
Twist 10.9 t.p.i.
Contraction, 1.1%
Yarn number (Worsted System) 20s

Singles yarn
Twist 10.3 t.p.i.
Yarn number (Worsted System) 38.9s

Summary of Yarn Construction (ASTM D-1244)

Warp yarn	38.9 : Z 10.3/2 : S 10.9 t.p.i.
Filling yarn	40.3 : Z 10.9/2 : S 10.7 t.p.i.

Based on this analysis, it was concluded that both warp and filling yarns are essentially identical in construction and are made by plying two ends of 40s worsted count yarn.

The tropical Air Force Standard fabric was analyzed spectrophotometrically using the I.D.L. Color Eye. Measurements were made using light source C and light source A. Color specifications are given below in terms of the tristimulus values X, Y, Z and chromaticity coordinates, x and y:

	Light Source C	Light Source A
X	0.0426	0.0453
Y	0.0405	0.0405
Z	0.0795	0.0239
x	0.2620	0.4000
y	0.2491	0.3700

An analysis was made of the spectrophotometric data supplied in a report prepared under Contract No. AF 33 (657) - 16558 entitled "Development of Shade Standard and Shade Tolerance in Blue 1549 Wool/ Polyester Cloth, Stock Dyed Conforming to Type III of Specification MIL-C-2115 B." The following conclusions are drawn from this analysis:

1. Shade tolerance levels, although established in the report, are not considered to be realistic being so small (less than one MacAdam color difference unit) that one could easily attribute the tolerance levels to random instrumental errors in making the spectrophotometric measurements.

2. The shade standard established under Contract No. AF 33 (657) - 16558 is radically different from the color standard used in this work. It is much lighter in shade indicating that more than one blue shade has been standard for uniform fabrics.

E. Critique of Current Practice in Manufacture of Uniform Fabrics Relative to Abrasion Behavior.

To establish current practice with respect to processing procedures for polyester/wool and current ideas with respect to the mechanism of frosting, polyester fiber producers, dyestuff manufacturers, and textile firms who produce polyester/wool worsted uniform fabrics were contacted. As far as the mechanism of frosting is concerned, little insight was gained from these contacts. One fiber producer, namely E. I. duPont de Nemours, supplied useful information relative to the abrasion of polyester/wool fabrics. Personnel of duPont in their examination of the same worn Air Force uniform examined in this study came to the conclusion that the change in appearance of the uniform referred to as frosting was due to the polyester component of the fabric. Their experimental results were in complete agreement with those described above. They also concluded that the mechanism of frosting is independent of the polyester fiber used although the magnitude of frosting will depend on the type polyester used.

1. Polyester Fiber.

Discussions with fiber producers and textile manufacturers revealed that at least four types of polyester fibers have been used in the manufacture of uniform fabrics. These various types are known to differ in their durability, toughness, and pilling resistance. Although they all meet the Military Specifications with respect to their chemical composition (polyethyleneterephthalate), it is known that some types are chemically modified, e.g., Dacron 64. It is also known that those types which are 100 per cent poly(ethyleneterephthalate) can differ greatly in their physical properties due to differences in the molecular weight of the polymer, molecular weight distributions, and spinning and drawing conditions employed which give rise to differences in the molecular order in the fibers and thus their mechanical properties. The duPont personnel recommended their Dacron 54 for application in uniform fabrics to minimize frosting because of its superior durability and toughness compared with other duPont fibers which have been used, namely Dacron 64, Dacron 59, and Dacron 35. Dacron 54 is a less fibrillating fiber. It was discovered that Dacron 64, a pill resistant fiber, is used in considerable amount for uniform fabrics although it is less tough than Dacron 54. In contrast with the recommendations of duPont, some fiber producers and dyers seemed to be in agreement that a pill-resistant fiber such as Dacron 64 would be preferred to a fiber like Dacron 54. It was concluded that there is more concern on the part of the textile manufacturers with respect to pilling than with respect to frosting.

With respect to the denier of the polyester, 3.0 denier per filament is specified. A 3.0 denier filament polyester fiber has a diameter of 17.5 μ. The wool grade specified is 64s or finer. The mean diameter of 64s wool fibers is about 21 μ. From the standpoint of spinning performance, wool and polyester fibers having approximately the same size would be preferred provided the use of a higher denier polyester fiber with 64s wool does not result in a yarn containing too few fibers (i.e., spinning limits not exceeded).

2. Composition of Polyester/Wool Blend

According to Military Specifications: MIL-C-21115G, the fiber blend specified consists of 55-60 per cent polyester fiber. Since the polyester fiber is primarily responsible for frosting, a decrease in the tendency to frost should result from a decrease in the polyester fiber content.

3. Yarn Size and Twist

The yarn size required by Military Specifications MIL-C-21115G is defined indirectly by the fabric weight, the number of yarns per inch in both the warp and filling, and the fabric construction (plain weave). Plied yarns are specified for Type II Class fabrics (9.0 oz. Tropical). The amount of yarn twist in the singles and plied yarns is not specified. Fiber mobility is an important consideration in pilling and would be expected to be important in frosting. An increase in yarn twist will lead to a decrease in fiber mobility.

4. Dyeing Procedures

Eight (8) dyestuff manufacturers were contacted. They were very helpful, supplying recommended dyes for both polyester and wool fibers, dyeing procedures, dye formulations for both fibers and spectrophotometric curves for some of their recommended dyes. The classes of dyes recommended are as follows:

Wool Component

a. milling acid dyes
b. acid metalized dyes
c. mordant dyes
d. neutral dyeing metalized dyes
e. soluble leuco vat dyes

Polyester Component

a. disperse dyes

Their dyeing recommendations indicated clearly that the preferred dyeing procedure is to dye each fiber component separately in top form instead of piece dyeing. Experience in the piece dyeing of polyester/wool fabrics in this program indicates the reasons for this preference:

a. Better control of color match with stock or top dyed fibers
b. No staining of wool by disperse dyes
c. In stock or top dyeing, the problem of poor dye penetration encountered in piece dyeing the high density worsted fabric is avoided

Standard wool dyeing procedures are used for the wool component. The recommended procedures for polyester are either atmospheric dyeing (at ~ 100°C) with the use of dyeing carriers or pressure dyeing (at ~ 130°C) with a small amount of dye carrier.

Frosting has often been attributed to "ring dyeing", that is, the dye has not penetrated the fibers sufficiently. "Ring-dyed" fibers will become lighter in shade on abrasion. Therefore, dyeing processing conditions must be those which result in sufficient fiber penetration by the dye with minimum damage to the fiber.

5. Finishing

In the finishing of polyester/wool worsted fabrics, carbonizing, a process for removal of cellulosic impurities, should be avoided if possible since it results in damage to both polyester and wool fibers leading to poorer abrasion resistance. Singeing is an important and necessary process required to minimize pilling tendency. Shearing also helps to minimize pilling tendency of the fabrics. Finishing processes which provide good fiber mobility such as fulling and dolly washing are important in producing fabrics with desirable hand.

In summary, it was concluded from a study of variables in the manufacture of polyester/wool uniform fabrics that the following factors are important in determining their abrasion behavior:

1. choice of polyester
2. size of polyester fiber relative to that of wool
3. composition of blend
4. dyeing procedure: stock or top dyeing versus piece dyeing, dye penetration into fiber
5. yarn twist (in singles and ply yarns)
6. chemical processes which result in fiber damage, e.g., carbonizing
7. singeing
8. processes in fabric finishing which provide fiber mobility

SECTION III

EXPLORATORY INVESTIGATION OF VARIABLES IN COMPOSITION AND PROCESSING OF UNIFORM FABRICS IMPORTANT IN FABRIC ABRASION

A. Type of Polyester Fiber

Based on a knowledge of those polyester fibers in current use in the manufacture of worsted fabrics, particularly uniform fabrics, and with a limited knowledge of their properties and structural parameters as they relate to abrasion resistance, four commercially available types were chosen for study, namely,

Dacron type 54
Dacron type 64
Dacron type 35
Dacron type 59

Although these fibers are made by one manufacturer, E. I. duPont de Nemours and Company, they represent variations in chemical composition, molecular weight, and stress-strain behavior typical of other commercially available polyester fibers.

The stress-strain curves for the four polyester fibers chosen for this work are shown in Fig. 5. Properties derived from these curves are given in Table 1.

TABLE 1

TENSILE PROPERTIES OF POLYESTER FIBERS**

Fiber	Elongation at break %	Breaking* Load(gm-wt)	Initial Modulus(g/den)	Energy to Rupture(gm-wt-cm)*
Dacron 54	43	14.9	29	3.1
Dacron 64	41	10.1	26	1.7
Dacron 35	44	10.5	47	3.3
Dacron 59	55	15.3	28	5.1

*For 3.0 denier filaments
**Method ASTM-D2101

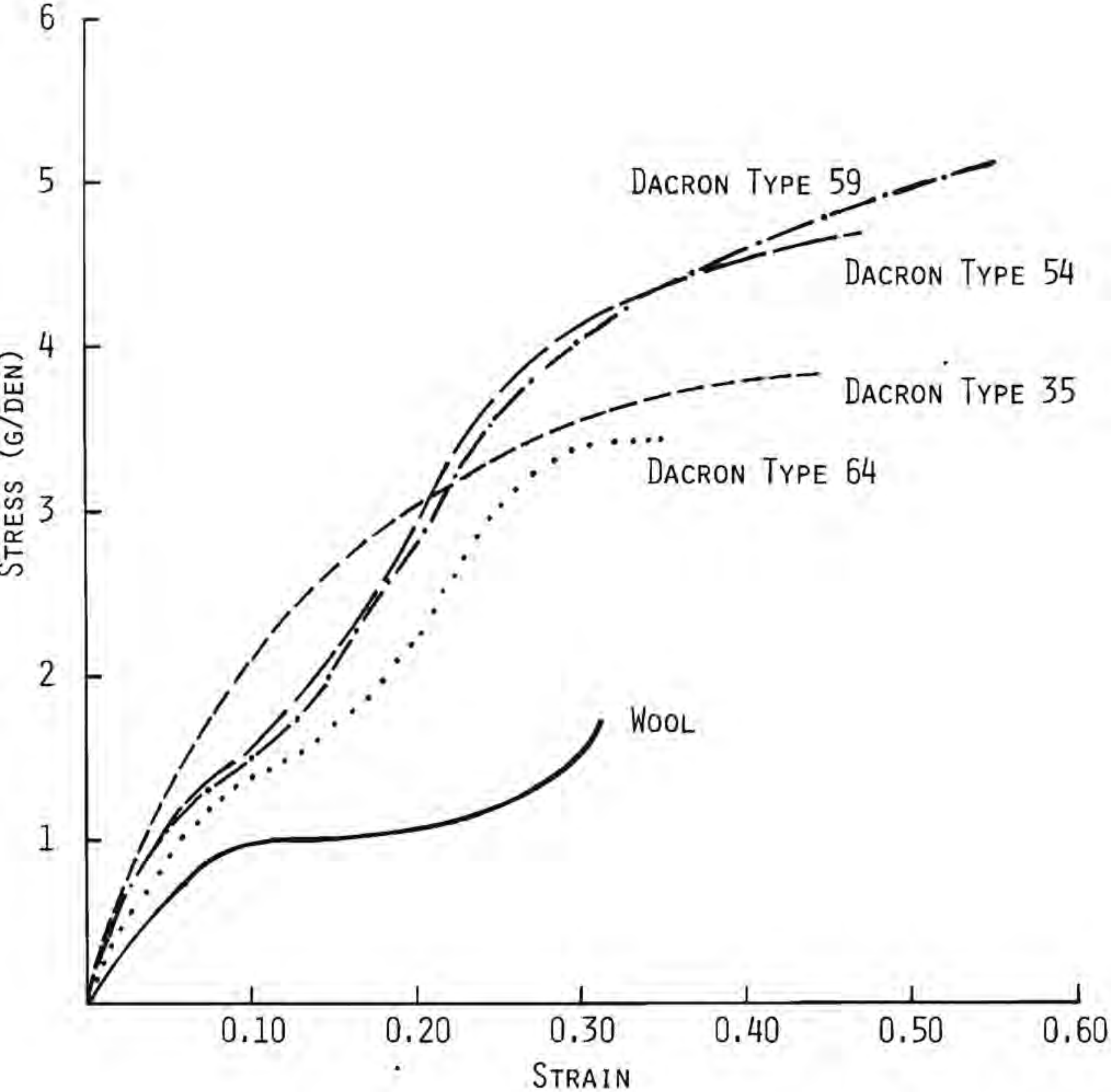

Figure 5. Stress-Strain Behavior of Polyester Fibers

The abrasion behavior of these fibers was determined using a fatigue apparatus capable of abrading single fibers under normal loads approximating those involved in standard flat-abrasion tests with speeds up to 1800 cycles per minute(17). The fibers were abraded against a tungsten wire (~ 8 mil diameter), the normal load being 200 mg. The fibers were abraded from one to ten hours (30 cycles/sec) and then examined by scanning electron and light microscopy. Noticeable damage to all fibers was obtained after one hour of abrasion. Although the extent of damage increased with increasing time of abrasion, the damage after ten hours was not as great as would be expected considering the amount of damage after one hour, probably due to the decrease in the force per unit area exerted on the filament by the abrading wire as the damage increased. It was concluded that an abrasion time of two hours was sufficient to estimate how the fibers were wearing relative to one another. The decreasing order of abrasion resistance was found to be Dacron 35 = Dacron 54 > Dacron 59 > Dacron 64. Dacron 64 stands out as having a much poorer abrasion resistance than the other fibers. Dacron 35 and Dacron 54 were very similar in abrasion resistance. Attempts were made to relate the abrasion resistance to mechanical properties, primarily initial modulus and energy to break. There is no clear relationship; however, the order of abrasion resistance does correlate with the energy to yield, decreasing as the energy to yield decreases. The very low energy to break for Dacron 64 probably accounts for its poor abrasion resistance.

Of more importance than the mechanical properties and abrasion resistance of the undyed, unfinished fiber as described above are the properties of the fibers after they have been dyed since it is in this state that the fibers exist in a uniform fabric. Therefore, the abrasion resistance was determined for Dacron 54 and Dacron 64 fibers which had been dyed. These two fibers were chosen because they represent extremes in abrasion resistance and also because they were believed to be the two fibers in common use for making uniform fabrics. Two dyeing temperature ranges were employed, name 125-135°C (pressure dyeing) and 95-100°C (atmospheric dyeing). These ranges are typically those used in dyeing polyester fibers.

Pressure Dyeing

1. 3% Carrier o.w.f. (Cindye DAC-888)
   Dyeing temperature 125°C
   Dyeing time 60 min.

2. 3% Carrier o.w.f. (Cindye DAC-888)
   Dyeing temperature 135°C
   Dyeing time 60 min.

Atmospheric Dyeing

Variables:

Dyeing temperatures	95°C and 100°C
Dyeing times	120 min. and 150 min.
Carrier - Cindye DAC-888 -	10.0 and 11.0% o.w.f.

The fibers dyed under pressure were found to be slightly less abrasion resistant than the undyed fibers with Dacron 64 showing more loss in abrasion resistance than Dacron 54.

The tensile properties of the dyed fibers are shown in Table 2.

TABLE 2

EFFECT OF DYEING ON TENSILE PROPERTIES **
(3-denier staple)

	Breaking Strength(g)	Breaking Elongation(%)	Work to Rupture(g-cm)	Initial Modulus(g/den)
Dacron 54				
Undyed	14.9	43	3.1	29
Dyed 125°C*	15.2	39	2.5	37
Dyed 135°C*	15.0	39	1.9	34
Dacron				
Undyed	10.1	41	1.7	26
Dyed 125°C*	9.8	29	1.1	32
Dyed 125°C*	10.6	31	1.2	33

*3.0% Carrier, 60 min.
**Method ASTM-D2101

The fibers dyed under atmospheric dyeing conditions also were poorer in abrasion resistance than the undyed fibers with Dacron 64 being poorer than Dacron 54. The most important factor in dyeing on abrasion resistance was found to be the amount of carrier employed, decreasing with increasing amounts of carrier used.

It was concluded from this work that the abrasion resistance of polyester fibers is reduced by dyeing. The severity of the dyeing conditions determines the magnitude of the loss in abrasion resistance, e.g., too high a dyeing temperature, extended times of dyeing, and excessive amounts of carrier. The loss in abrasion resistance indicated that redyeing due to off-shades will only lead to a further decrease in abrasion resistance and should never be done if one is to obtain optimum abrasion resistance.

The conditions used in abrading polyester fibers, namely 30 cycles/sec, 2 hours, with a normal force of 200 mg, could not be used to evaluate wool fibers due to their poorer abrasion resistance. Therefore, the time of abrasion was reduced to fifteen minutes. Eight wool fibers, 64s Grade, were abraded and only five fibers survived. Microscopically, it was apparent that approximately one-half of the fiber abraded away.

It was expected that the observed single filament abrasion behavior of wool and the polyester fibers would be translated to the blend uniform fabric.

B. Denier of Polyester Fiber and Grade of Wool

No study was made of the effect of the denier of polyester fiber and grade of wool on abrasion behavior. From discussions with fiber producers, it was concluded that improved abrasion resistance would be predicted for a polyester/wool blend in which the size (diameter) of the polyester fiber more nearly matches the size of the wool fiber as specified, namely 64s wool or finer. Currently, 3.0 denier polyester is specified and used along with 64s wool in uniform fabrics. A 4.5 denier polyester filament more nearly matches in size 64s wool fibers:

	Diameter(μ)
3.0 denier polyester	17.5
4.5 denier polyester	21.4
64s wool	21.3

C. Fiber Content of Fabric

In view of the mechanism of frosting, it would be expected that the frosting of polyester/wool fabrics could be reduced by increasing the wool content of the blend. Therefore, in the experimental fabric program to determine those factors important in abrasion behavior, the fiber content was varied from 60/40 polyester/wool to 40/60 polyester/wool.

D. Selection of Dyes

In order to achieve the Air Force Blue 1549 on both polyester and wool fibers which meet the standards of color specification and fastness requirements, careful selection of dyes is required. Most types of polyester fibers can be dyed only with disperse dyes. Those fibers such as Dacron 64 which contain acid groups can be dyed with cationic dyes; however, the light fastness of these dyes is not sufficient to meet the requirements for uniform fabrics. The wool component can be dyed with acid dyes including all types of acid dyes (leveling acid, neutral dyeing milling, acid metalized, neutral dyeing metalized, and chrome). The dyes which have been found to be suitable for application are given in Tables 3 and 4.

TABLE 3

DISPERSE DYES FOR POLYESTER FIBERS

Name	C. I. Name	Manufacturer*
Foron Blue E-R	Disperse Blue 20	S
Foron Rubine SE-GLF	Disperse Red 73	S
Foron Yellow E-RGFL	Disperse Yellow 23	S
Resolin Blue FBL	Disperse Blue 56	V
Resolin Red BRL	Disperse Red 134	V
Resolin Orange 3GL	Disperse Orange 66	V
Eastman Poly Blue FLG	Disperse Blue 27	ECP
Eastman Poly Blue BLF	Disperse Blue 120	ECP
Eastman Poly Blue 4RL	Disperse Blue 64	ECP
Eastman Poly Red FFBL	Disperse Red 60	ECP
Eastman Poly Yellow G-LSW	No Listing	ECP
Genacron Blue BGL	Disperse Blue 120	GAF
Genacron Cerise B	Disperse Red 59	GAF
Genacron Yellow GGLL	Disperse Yellow 48	GAF
Latyl Blue LS	Disperse Blue 62	duP
Latyl Brill. Blue BG	Disperse Blue 60	duP
Latyl Violet BN	Disperse Violet 27	duP
Latyl Cerise B	Disperse Red 59	duP
Latyl Yellow YLW	Disperse Yellow 42	duP
Latyl Violet 2R	Disperse Violet 18	duP

*S - Sandoz
V - Verona
ECP - Eastman Chemical Products
duP - duPont
GAF - General Aniline and Film

TABLE 4

DYES FOR WOOL

Name	C. I. Name	Manufacturer*
Levelan Navy Blue IRL	No Listing	V
Levanol Brilliant Blue FFG	Acid Blue.....	V
Isolan Orange R	....	V
Isolan Yellow NW	Acid Yellow	V
Acid Chrome Blue RRA	Mord. Blue 9	GAF
Metomega Chrome Cyanine BLL	Mord. Blue 7	S
Omega Chrome Black Blue G	No Listing	S
Metomega Chrome Bordeaux 2BL (Pat)	No Listing	S
Metomega Chrome Yellow ME	No Listing	S

*V - Verona
GAF - General Aniline and Film
S - Sandoz

The dyes in these lists should not be construed to be the only ones suitable for dyeing wool and polyester fibers for uniform fabrics.

Laboratory dyeings were made on Dacron 54 and Dacron 64 using a pressure dyeing procedure at 125°C and dyeing formulations recommended by General Aniline and Film, Sandoz, and E. I. duPont de Nemours. The color differences between these dyeings and the Air Force Standard are shown in Figure 6 as total lightness difference (ΔL) and total color difference (ΔE) with both ΔL and ΔE being expressed in MacAdam units. The chromaticity differences (ΔC), not shown in Figure 6, contribute negligibly to the overall color differences, ΔE. These results show that dyeing formulations could be readily adjusted to duplicate the Air Force Standard. It was further concluded that dye formulations could be easily developed which preclude the use of small, "pinch" quantities of any one component of the dye formulation.

E. Effect of Dyeing Conditions on the Color Yield and Tensile Properties of Polyester Fibers.

1. Dyeing Conditions and Color Yield

In the dyeing of polyester fibers, two alternative dyeing procedures are usually employed:

a. Atmospheric dyeing at a temperature of approximately 100°C with the use of dyeing "carriers" in amounts from 10 to 15 per cent based on the weight of fiber to be dyed.

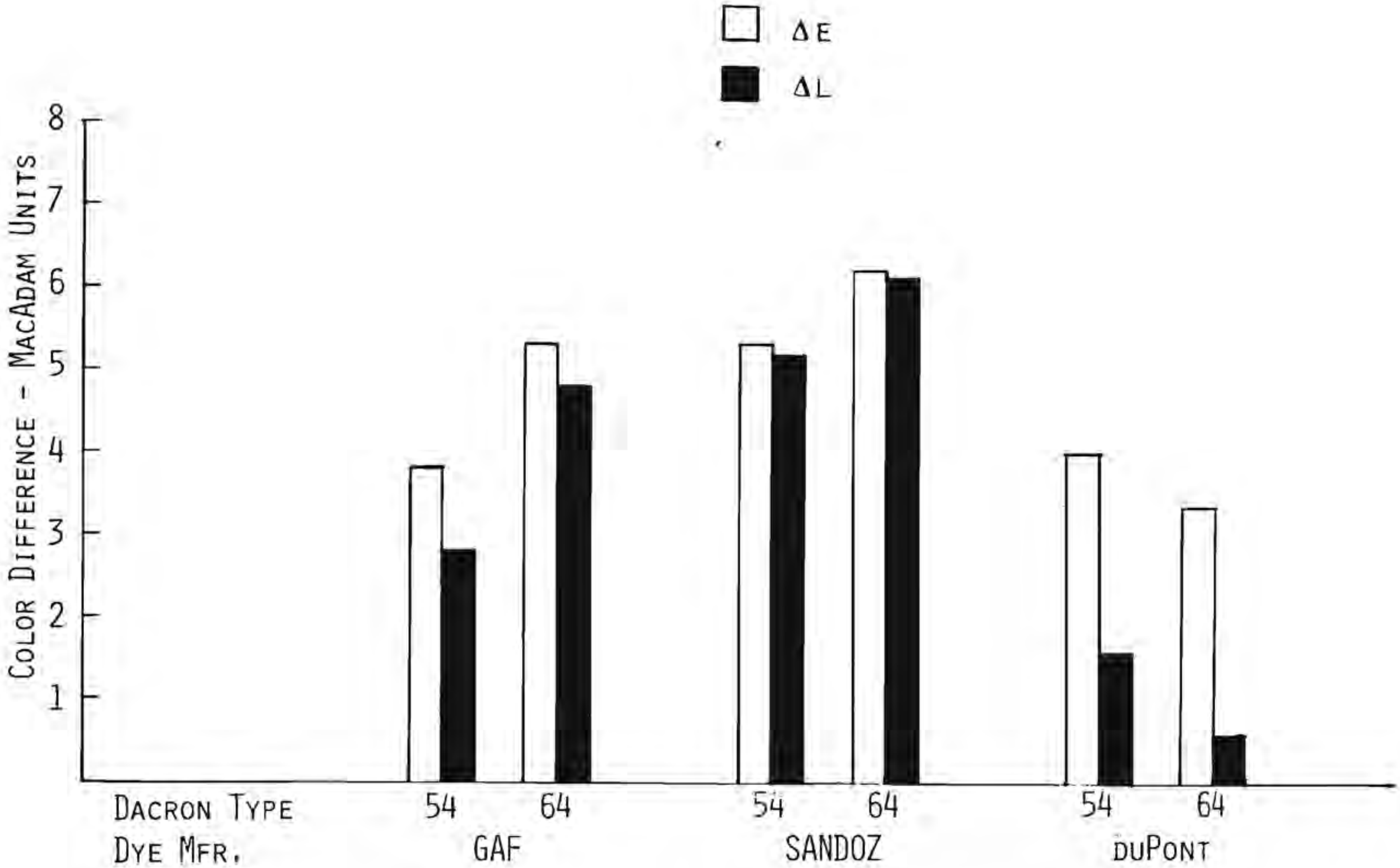

FIGURE 6. COLOR DIFFERENCE BETWEEN AIR FORCE TROPICAL SHADE AND LABORATORY DYEINGS USING RECOMMENDED DYEING FORMULATIONS

b. Pressure dyeing at a temperature of 120° to 135°C either with no dyeing carrier or approximately 3 per cent based on the weight of fiber to be dyed.

The latter procedure is preferred because of shorter dyeing cycles but there is the requirement of dyeing equipment which can be pressurized. Many dyehouses do not possess this equipment. The variables which affect color yields and mechanical properties are the dyeing temperature, dyeing time, and the amount of carrier used, deterioration in polyester fiber properties increasing with increases in each of these variables.

In this study, a disperse dye typical of the blue component in the Air Force Blue 1549 shade, namely Latyl Blue LS (E. I. duPont de Nemours and Co.) was chosen. The assumption was that the other dyes necessary for producing the Air Force shade will behave similarly.

The following conditions were used:

Atmospheric Dyeing

Temperature °C	95°, 100°
% Carrier (based on fiber weight)	9.0, 10.0, 11.0
Dyeing time (min.)	60, 120, 150

Pressure Dyeing

Temperature °C	120°, 125°, 135°
% Carrier (based on fiber weight)	0.0, 3.0
Dyeing time (min.)	30, 60, 90

The carrier used in these dyeings was Cindye DAC-888, a butylbenzoate carrier sold by Cindet Chemicals, Inc., and recommended for both atmospheric and pressure dyeing of polyester fibers. It should be noted that the experiments for atmospheric and pressure dyeing are factorially designed (3 x 3 x 2) making possible a statistical treatment of the responses.

For the dyeings made under pressure, the variation in color yield with variations in dyeing time, dyeing temperature, and carrier is shown in Figure 7. Total lightness difference (ΔL), expressed in MacAdam units, is plotted in Figure 7 since any color differences are due primarily to lightness differences. All dyeings were compared with a standard dyeing, namely, 125°C, 60 min., 3.0% carrier. Figure 7 shows clearly that the effect of time and temperature of dyeing on color yields is much smaller in the presence of carrier than when no carrier is used. Statistical treatment of the color data showed that the most important factors affecting color yield were the carrier and dyeing temperature. The interaction of

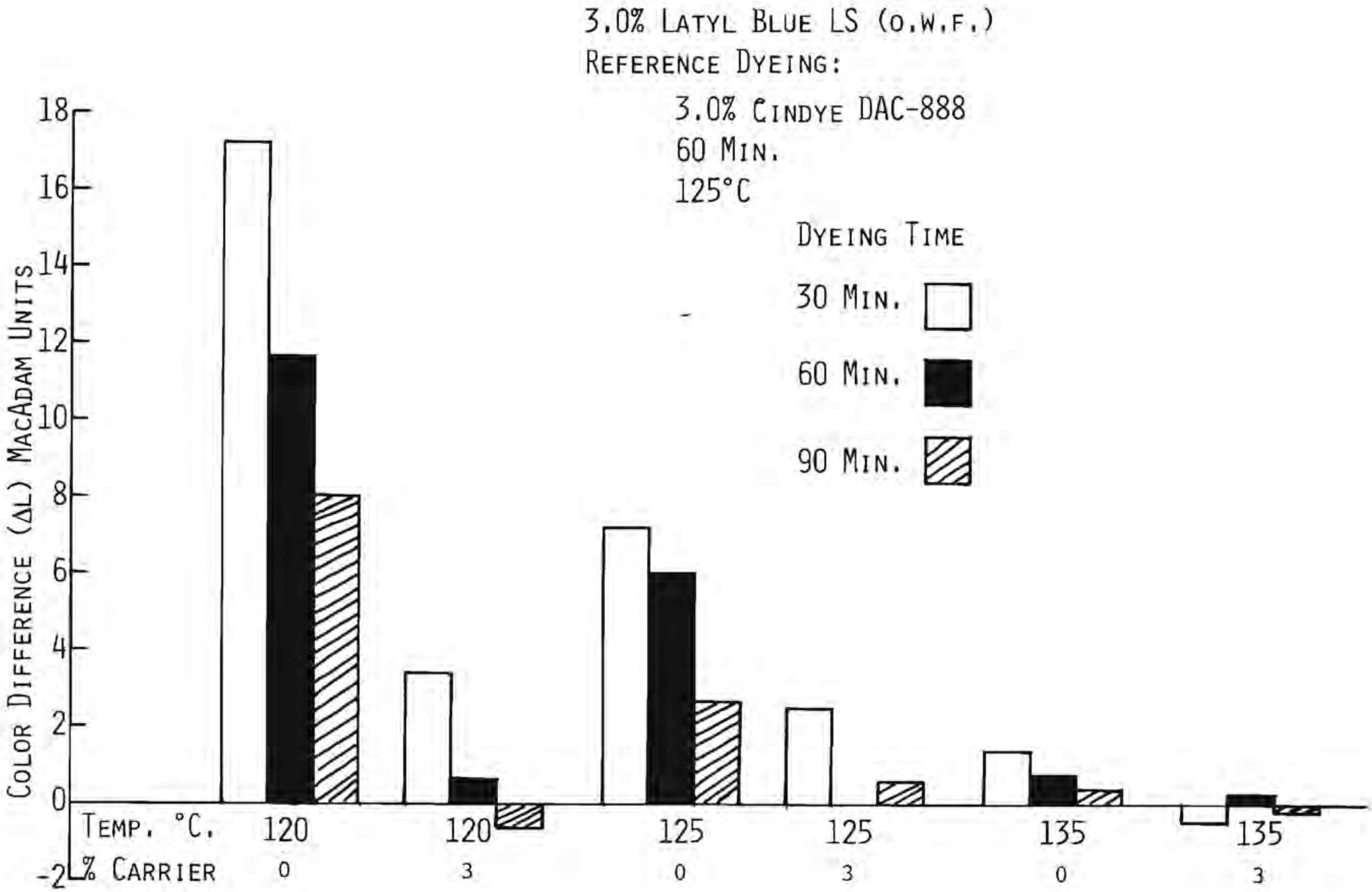

Figure 7. Effect of Time, Temperature, and Amount of Carrier on Color Yield in Pressure Dyeing of Polyester Fibers.

these two factors was also found to be important. The following alternate procedures are recommended:

1) 3.0% carrier (DAC-888)
   120°C
   90 min.

2) 3.0% carrier (DAC-888)
   125°C
   60 min.

For atmospheric dyeings made at 95° and 100°C, the reference dyeing to establish the effect of carrier, temperature and time of dyeing on color yields, was 100°C, 10% carrier, 120 min. The results are shown in Figure 8. It can be seen that all of the dyeings carried out at 95°C are 1-6 MacAdam units lighter than the standard reference while most of those carried out at 100°C closely approximate the results obtained under the dyeing conditions used for the standard. A statistical treatment of the data shows that within the practical dyeing limits in the experimental design, the only significant factor affecting color yield was the dyeing temperature.

The dyeings made under atmospheric conditions, 95° and 100°C, were found to be approximately four MacAdam units lighter (ΔL) than those made under pressure (120°, 125°, 135°C). This means that dyeings made under atmospheric conditions will require approximately ten (10) per cent more dye than those under pressure to arrive at equivalent shades.

2. Dyeing Conditions and Tensile Properties

The tensile properties have been determined for both Dacron 54 and Dacron 64 dyed under the pressure dyeing conditions described above. The results are shown in Table 5.

Inspection of the data shows clearly that both fibers exhibit an appreciable loss in work to rupture (30 to 40% loss) as a result of dyeing. The dyed Dacron 54 has a work to rupture approximately twice that of the dyed Dacron 64. This ratio of 2 to 1 is also shown by the undyed fibers.

Both of the dyed fibers have lower elongations at break than the undyed fibers being more pronounced with Dacron 64. Slight increases in modulus were noted for both fibers. A statistical analysis of the breaking load data shows that the interaction of the factors, per cent carrier and dyeing temperature, was significant at the 99% confidence level. Thus, an increase in the dyeing temperature coupled with an increase in the amount of carrier leads to a decrease in the breaking load. No tensile properties were determined for fibers dyed under atmospheric conditions; however, the abrasion properties were measured and the results have been described in Section II.

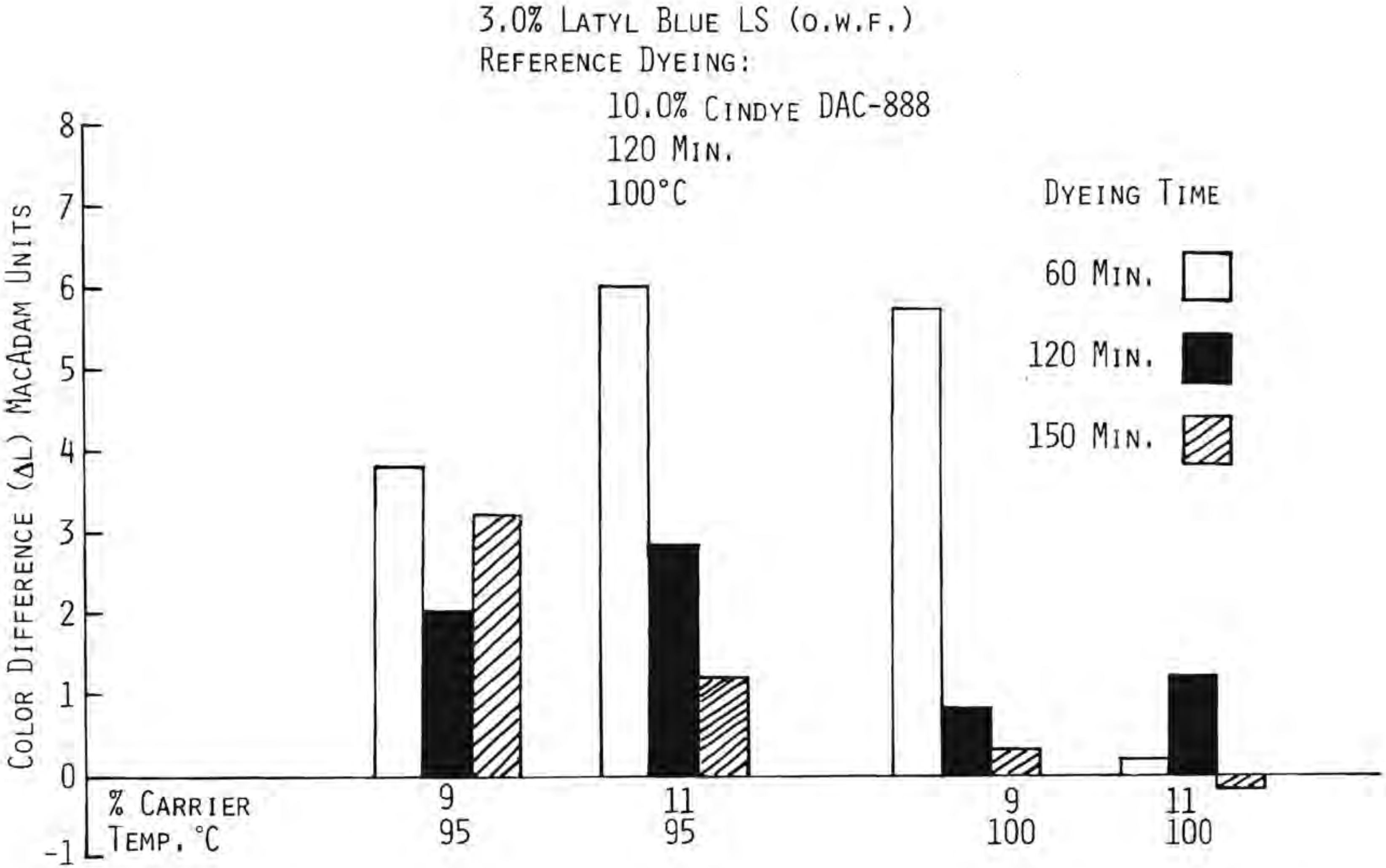

Figure 8. Effect of Time, Temperature, and Amount of Carrier on Color Yield in Atmospheric Dyeing of Polyester Fibers

TABLE 5

EFFECT OF DYEING CONDITIONS ON TENSILE PROPERTIES OF POLYESTER FIBERS

Treatment			Dacron 54				Dacron 64			
			Breaking Strength (g)	Breaking Elongation (%)	Work to Rupture (g-cm)	Initial Modulus (g/den)	Breaking Strength (g)	Breaking Elongation (%)	Work to Rupture (g-cm)	Initial Modulus (g/den)
After Dyeing: T°C	Time (min)	Carrier (%)								
Before Dyeing			14.9	43	3.1	29	10.1	41	1.7	26
120	30	0	15.5	41	2.4	30	9.7	26	1.0	34
120	30	3	14.2	34	1.8	39	10.2	33	1.5	33
120	60	0	13.7	35	1.8	32	9.5	31	1.2	31
120	60	3	14.8	46	3.2	30	10.4	28	1.1	36
120	90	0	14.9	33	1.8	30	9.9	30	1.2	30
120	90	3	12.9	36	1.5	27	9.3	29	1.1	30
125	30	0	13.7	40	2.4	27	10.0	32	1.0	27
125	30	3	15.6	41	2.7	33	9.9	28	1.1	32
125	60	0	14.1	38	2.1	29	9.0	29	0.8	25
125	60	3	15.2	39	2.5	37	9.8	29	1.1	32
125	90	0	13.9	33	1.6	44	8.2	25	0.7	28
125	90	3	16.8	41	2.7	35	9.8	28	1.0	33
135	30	0	14.7	37	1.6	34	8.3	27	1.0	37
135	30	3	15.3	41	3.0	34	9.5	29	1.0	39
135	60	0	14.7	38	2.6	38	9.9	29	1.1	33
135	60	3	15.0	39	1.9	34	10.6	31	1.2	35
135	90	0	14.6	36	1.4	36	9.7	31	1.2	29
135	90	3	15.8	39	2.9	34	8.6	27	0.9	30

F. Conclusions from Exploratory Studies - Basis for Experimental Fabric Program.

In order to determine those variables in the composition and processing of uniform fabrics, exploratory studies were made as described above with emphasis on

(1) choice of polyester fiber

  a. tensile properties
  b. abrasion properties

(2) dyeing conditions

  a. color yield
  b. effect on tensile properties
  c. effect on abrasion properties
  d. stock or top dyeing versus piece dyeing

As a result of these studies and a critical assessment of other factors in the yarn and fabric structure and processing conditions (primarily fabric finishing) used to produce a more durable uniform fabric, it was concluded that the following factors must be considered:

(1) type of polyester
(2) grade of wool
(3) denier of polyester fiber, staple length, crimp
(4) stock or top dyeing versus piece dyeing
(5) atmospheric versus pressure dyeing of polyester fiber
(6) composition of blend, degree of blending
(7) yarn size
(8) singles versus ply yarns
(9) amount of twist in yarns
(10) singeing of fabric
(11) amount of fabric fulling
(12) carbonizing of fabric
(13) decating of fabric
(14) shearing of fabric

It would be a formidable task to exhaustively evaluate each of these factors. Therefore, one must arrive at those factors which are likely to be most important in determing the fabric abrasion behavior, particularly pilling and frosting behavior. It was concluded that certain of these factors should not be considered in an experimental fabric program. For example, it is obvious that pilling and frosting will be reduced if the fabric is well singed and sheared since both of these processes will result in fabrics which are less "hairy" and therefore less susceptible to pilling and frosting. Likewise, fulling and decating processes are common to all wool processing and should not be a variable in an experimental fabric program. On the other hand, evaluation of uniform fabrics now in use has indicated that more than one type of polyester has been used. On the basis of the study made on different types of polyester fibers as described above, it was concluded that this variable in the composition of uniform fabrics should be included in the experimental fabric program.

The following factors were chosen for study in the experimental fabric program:

(1) Type of polyester fiber
(2) Denier of polyester fiber
(3) Grade of wool
(4) Carbonizing of fabric
(5) Relative amounts of wool and polyester fibers in blend
(6) Yarn twist
(7) Singeing

A description of the experimental fabric program follows in Section IV.

SECTION IV

EXPERIMENTAL FABRIC PROGRAM TO DELINEATE EFFECTS OF VARIABLES IN COMPOSITION AND PROCESSING OF UNIFORM FABRICS ON FABRIC PERFORMANCE

A. Description of Experimental Fabric Program

The experimental fabric program to sort out the effects of variables in the production of polyester/wool uniform fabrics on their abrasion resistance was based on information obtained from several sources:

(1) Discussions with fiber and textile manufacturers as well as manufacturers of dyes and dyeing assistants
(2) Technical information available from fiber manufacturers
(3) Literature in technical journals related to fiber and fabric abrasion (pilling and frosting) and
(4) Work previously done in this program.

It was concluded that the variables which should be investigated in a statistically designed experiment were as follows:

(1) Polyester type
(2) Grade of wool
(3) Relative amounts of wool and polyester in blend
(4) Yarn twist
(5) Carbonizing
(6) Denier of polyester fiber

To minimize the number of fabrics required for this experiment, it was decided that the basic design would be a 2^5 design, the five variables being the first five listed above at two levels for each variable. A fractional factorial experiment (5 factors in 8 observations) was performed, i.e., eight (8) fabrics. The production of four additional fabrics made possible an evaluation of an additional level for variable 1 (polyester type) and variable 4 (yarn twist) as well as an evaluation of the effect of the denier of the polyester fiber on abrasion.

The variables and levels for each variable arranged in decreasing order of their estimated importance in abrasion were as follows:

Variable	Level −	Level +
A. Polyester Type (3 denier)	Dacron 64	Dacron 54
B. Grade of Wool (Domestic)	64's	64-70's
C. Carbonizing	yes	no
D. Composition of Blend-Polyester/Wool	60/40	40/60
E. Yarn Twist (t.p.i.)	12	15

The experiments performed are described below:

Fractional Factorial for 2^5 Design (1/4 replicate)

Equate D to ABC
E to -BC

	A	B	C	D	E	Treat. Comb.	Effects and Aliases
F 1	−	−	−	−	−	1	A, -DE
F 2	−	−	−	+	−	ad	B, -CE
F 3	−	+	−	+	+	bde	C, -BE
F 4	+	+	−	−	+	abe	D, - AE
F 5	−	−	+	+	+	cde	E, -BC, -AD
F 6	+	−	+	−	+	ace	AB, CD
F 7	−	+	+	−	−	bc	AC, BD
F 8	+	+	+	+	−	abcd	

$D(D=ABC) = (D^2=ABCD) = (I=ABCD)$

$E(E=BC) = (E^2=-BCE) = (I=-BCE)$

$(ABCD)\ (-BCE) = -ADE$

defining contrasts I, ABCD, -BCE, -ADE

aliases - (i) A, BCD, -ACE, - DE
(ii) B, ACD, -CE, -ABDE
(iii) C, ABD, -BE, -ACDE
(iv) D, ABC, -BCDE, -AF
(v) E, ABCDE, -BC, -AD
(vi) AB, CD, -ACE, -BDE
(vii) AC, BD, -ABE, -CDE

Notes:

(1) In order to obtain additional information concerning the effect of yarn twist, the composition corresponding to F-6 in the design was converted to two additional fabrics in which the yarn twist was 12 tpi and 18 tpi. The fabrics produced from these yarns were designated F-9, and F-10 respectively.

(2) In order to determine the effect of polyester denier, another fabric was prepared in which a 4.5 denier Dacron 54 replaced the 3.0 denier Dacron 54 in the sample described as F-6. This fabric was designated F-11.

(3) It was desirable to evaluate another polyester fiber, whose properties differ from those of Dacron 54 and Dacron 64. To accomplish this, a fabric sample was prepared in which 3.0 denier Dacron 35 replaced the 3.0 denier Dacron 54 in the sample described as F-6. This fabric was designated F-12.

In summary, ten different blended polyester/wool tops were prepared from which twelve sample fabrics were made.

A complete description of the fabrics produced is shown in Figures 9, 10, and 11. Approximately fifty (50) yards of each fabric were prepared, one-half of which was singed in finishing. The remaining one-half was not singed.

The companies who supplied the necessary services for producing the experimental fabrics were as follows:

(1) Source of wool tops and polyester tops:

Wellman, Incorporated
Johnsonville, South Carolina

(2) Dyeing and blending of dyed tops:

Florence Dye Works
Woonsocket, Rhode Island

(3) Spinning of yarns from dyed and blended tops:

Westbrook Spinning Company
Westbrook, Maine

(4) Weaving of fabrics:

Textile Research Services
Raleigh, North Carolina

(5) Finishing of Fabrics

Florence Finishing Company
Woonsocket, Rhode Island

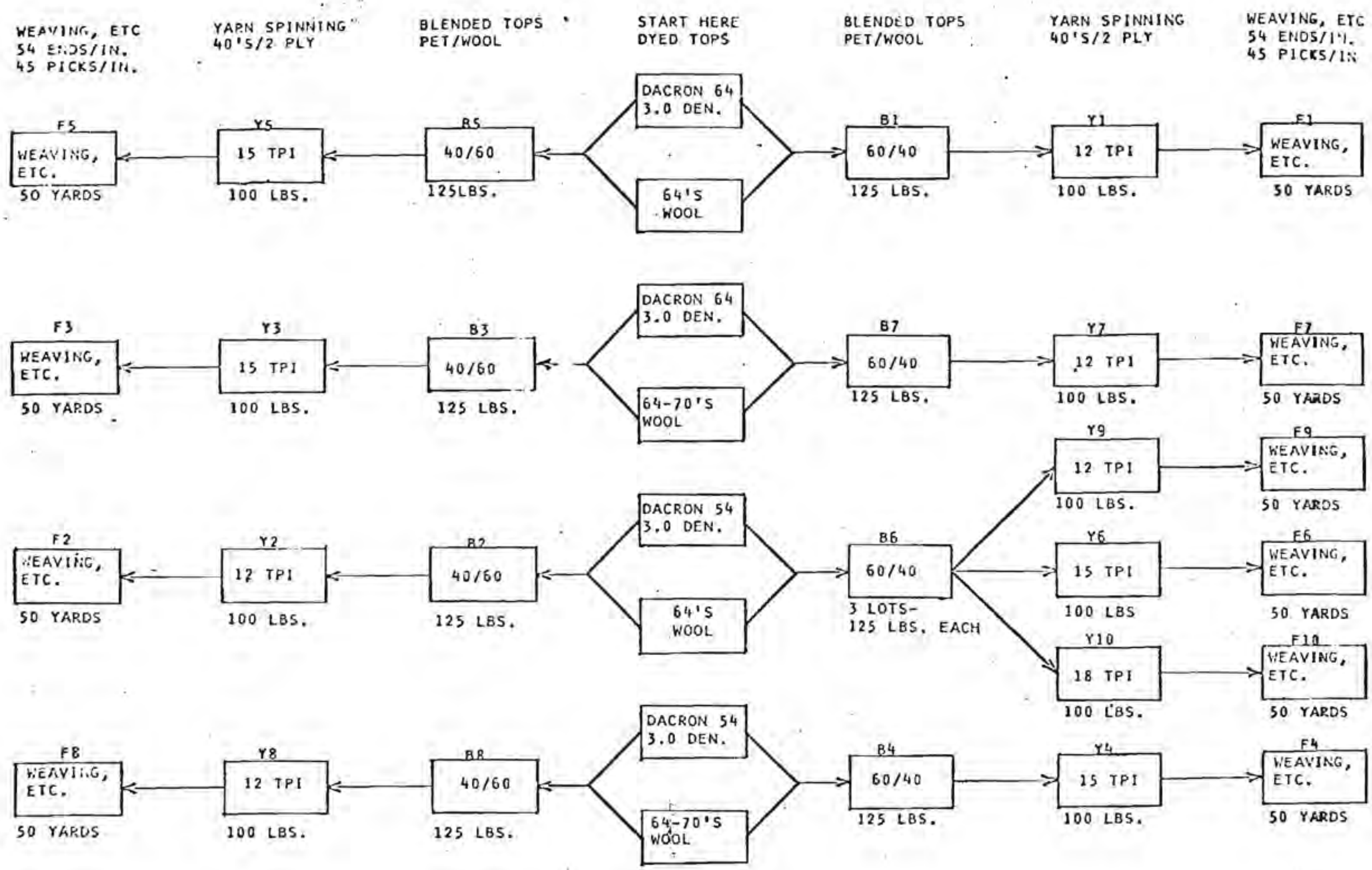

FIGURE 9. FLOW CHART FOR EXPERIMENTAL FABRICS F-1 THROUGH F-10

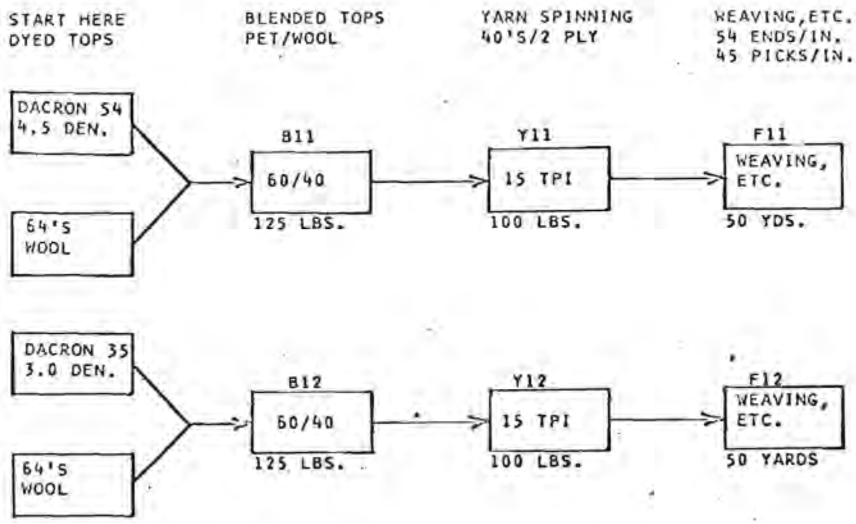

FIGURE 10. FLOW CHART FOR EXPERIMENTAL FABRICS F-11 AND F-12

FABRICS

F-1
F-2
F-3
F-4

→ Carbonized

F-5
F-6
F-7
F-8
F-9
F-10
F-11
F-12

→ Finishing was same for all fabrics after fabrics, F-1, F-2, F-3, and F-4 had been carbonized, i.e., standard finishing for tropical worsted uniform fabrics

Note: Fifty (50) yards of each fabric were produced, one-half of which were singed in finishing.

FIGURE 11. FLOW CHART FOR FABRIC FINISHING

B. Description of Processing Conditions

The processing conditions used in the preparation of these fabrics as well as the yarn and fabric constructions have been judged to be the same as those described in the Military Specifications, MIL-C-21115G. In these specifications, details of fabric construction are given but there is no specification of yarn twist. In this program, yarn twists of 12,15, and 18 t.p.i. were used whereas, the Air Force Tropical Standard fabric was shown to have a twist of 10-11 t.p.i. in both the singles and plied yarn. The Military Specifications call for the use of a 3.0 denier per filament polyester fiber, the composition of which must be essentially poly (ethyleneterephthalate). This allows the textile manufacturer to use a variety of polyester fibers differing in molecular weight of the polymer from which they are produced, differing in degrees of molecular order, and differing in chemical composition, e.g., cationic dyeable polyester fibers. From an examination of three different Air Force standard fabrics, it was discovered that the polyester fibers used did indeed differ in their chemical composition, i.e., both cationic and non-cationic dyeable polyester fibers were used in their production.

With the exception of the weaving of the experimental fabrics, all processing was carried out on commercial size equipment by industrial firms familiar with and actively engaged in the production of 100 per cent wool and polyester/wool worsted fabrics.

A schematic flow chart for the processing of polyester tow and combed wool top to finished fabric is shown in Figure 12.

The polyester tow was first processed through a Pacific converter, 3.5 inch straight cut, and then converted to top. The polyester and wool tops were dyed separately. Each blend of the dyed tops was given three gillings (Warner Swasey pin drafters) followed by combing (French P.L. combs). After combing, the blends were given one gilling followed by one passage through a Holdsworth Leveller and one final gilling. The blends were then spun into yarn as follows:

1. drawing -3 processes
2. roving
3. spinning
4. twisting (plying)

Since the yarns produced were plied yarns, the specified twist in the singles and ply yarns was such that there was a balance of twist, being slightly higher in the ply yarn than in the singles yarn.

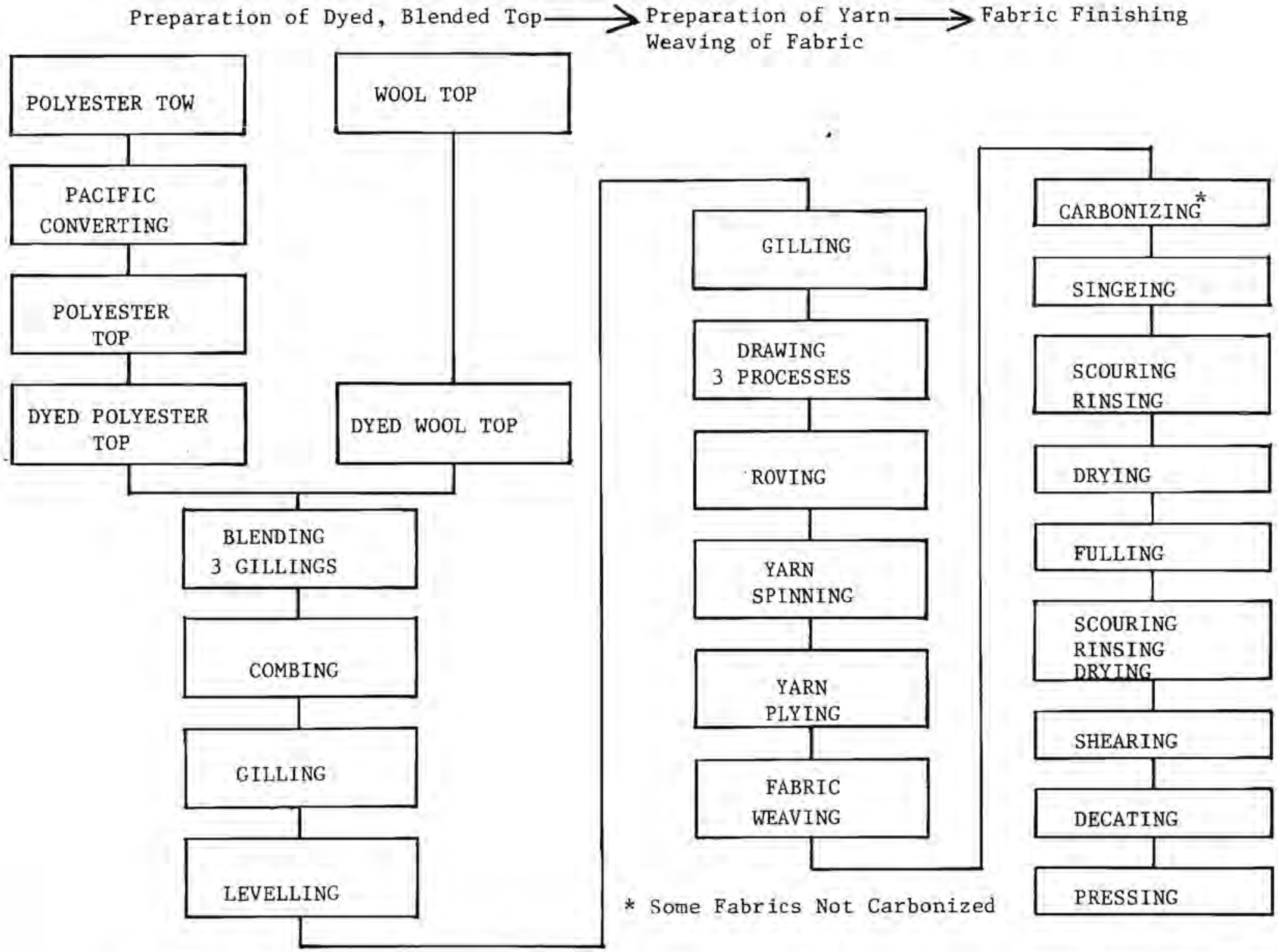

FIGURE 12. FLOW CHART FOR PROCESSING POLYESTER TOW AND COMBED WOOL TOP TO FINISHED FABRIC

The fabric construction was the same as that described in the Military Specifications, MIL-C-21115G, for Type III, Class 1 polyester/wool fabric.

The wool and polyester tops were scoured and dyed separately in Frederick Type kettles with one way circulation at atmospheric pressure. The wool was dyed with premetalized dyes and the polyester with disperse dyes using the carrier Dilatin TC. The dyeing formulations were as follows:

Wool Component

0.95% Levalan Navy Blue IRL
0.38% Levanol Brilliant Blue FFG
0.075% Isolan Orange R
0.072% Isolan Yellow NW

5.0% Ammonium Sulfate
1.0% Avalon IS

Polyester Component

3.00% Foron Blue
0.46% Foron Yellow E-RGFL
1.25% Foron Brilliant Red E-2BL

1.00% Lyogen P
1.00% Lyogen DFT
12.00% Dilatin TC

2.0 hrs. at 212°F

After Scour:

2.00% sodium hydrosulfite
2.00% caustic soda
1.00% Ekaline G-80

20 min. at 160°F

All dyed tops were then scoured through a four bowl backwasher. Bowls one and two were set at 100°F and charged with a synthetic detergent adjusted to a pH of 9.5 with ammonia. Bowls three and four were clear water rinses with the rinse bath set at 100°F. The temperature of the backwasher dryer did not exceed 240°F. As the dried top emerged from the dryer, it was given an application of Goulston Static Nil for lubricity and static control (1.25% on wool tops and 0.25% on polyester tops). These dyed tops were then blended as specified in Figures 9 and 10.

The twelve woven fabrics were finished as shown in Figure 12. All fabrics were first crabbed in the greige on a four bowl crab to avoid cockling and cracking of the fabrics in finishing. As noted in Figure 11, four of the fabrics, F-1, F-2, F-3 and F-4 were carbonized. The carbonized pieces were neutralized with soda ash before further processing.

The twelve fabrics were then scoured in a stainless steel dolly washer at 90°F for thirty minutes using a synthetic detergent and soda ash. The goods were then rinsed for one hour using cold water. They were then passed through a scutcher, passed through squeeze rolls set at ten tons pressure and dried on a pin tenter dryer set at 230°F. The fabrics were then sheared, once on the back and twice on the face. The next operation was semi-decating, two minutes steaming and five minutes cold pumping. The fabrics were then pressed lightly to remove wrinkles. This was followed by a final examination on the finish perch.

Initial examination of the finished fabrics with respect to flat-abrasion behavior indicated that the fabrics had too much cover which resulted in excessive pilling. Therefore, one-half of each of the fabrics was returned to the finisher for singeing. The singeing operation was followed by the usual finishing operations.

C. Experimental Methods Used in the Evaluation of Experimental Fabrics at Each Stage in Processing

Since there were several steps involved in processing polyester tow and wool top to finished fabric, it was considered important to evaluate the materials at each stage of processing, that is, the dyed wool and polyester tops, the dyed and blended tops, the yarn made from the blended tops, and the yarns and fabrics produced from the blended tops. Table 6 lists the property, title of the standard test, and its source (Federal Standards 191 - , A.S.T.M., or A.A.T.C.C.) for the various test methods used on the materials.

In addition to these standard tests, additional tests were performed to assess the abrasion properties of the fabrics:

1. Multiple tests to determine color change due to flat abrasion (frosting).
2. Flat abrasion tests after dry-cleaning 10, 20, and 30 times using two dry-cleaning solvents, namely Stoddard solvent and perchloroethylene.
3. polyester identification - extraction and staining technique

In most of the testing of the experimental fabrics, the standard method calls for more than one measurement to be made. The most common number of measurements was five (5). Therefore, it was possible to analyze the data statistically using a Hewlett-Packard program available for a two-way analysis of variance with replicates (18). In this program, two variables are considered at a time. For these two variables, the program compares the mean values for the two variables and their interaction. Since the experimental design included 5 variables, there are ten (10) possible pairs of variables that must be considered in the analysis. An F table was used to interpret the significance (confidence limits) for the variables studied:

Confidence Limits for Statistical Analysis

v_1/v_2

$(1-\alpha)$*	$^1/_4$	$^1/_{12}$	$^1/_{36}$
		F Value Expected	
0.75	1.81	1.46	1.36
0.90	4.54	3.18	2.84
0.95	7.71	4.75	4.08
0.99	21.20	9.33	7.31

*Level of Significance

D. Experimental Results and Discussion of Results

1. Analysis of Dyed Polyester and Wool Tops

The weights (linear density) of the dyed tops were determined as shown in Table 7. Color measurements made on hand carded samples of each top are shown in Table 8. All of the tops have approximately the same color with the exception of the Dacron 54 (4.5 denier) which is darker in shade. Single filament properties including denier per filament, breaking strength (g/den.) and breaking elongation (%) were determined. Forty fiber specimens of each sample were tested. The results are shown in Table 9. With the exception of Dacron 54 (3.0 denier), the denier of the polyester fiber was found to be 5-10 per cent higher than the quoted denier for the purchased undyed fiber. These higher values are most probably due either to sampling or, more likely, to fiber relaxation in dyeing. With respect to breaking strength, Dacron 54 (3.0 denier) and Dacron 54 (4.5 denier) are equivalent (4.35 g/den.) and 4.20 g/den respectively) and higher than that of Dacron 64 (3.0 denier) and Dacron 35 (3.0 denier), 3.10 g/den and 3.31 g/den. respectively. The wool fibers have much lower breaking strength than the polyester fibers as expected. The 4.5 denier Dacron 54 was found to have a higher breaking elongation than 3.0 denier Dacron 54, 36% and 28% respectively. The breaking elongations for the Dacron 35 and Dacron 64 were even lower, 25% and 22% respectively.

TABLE 6

TEST METHODS USED ON TOP, YARNS AND FABRICS

Property	Title	Test Method ASTM, AATCC Federal Standard 191-
Dyed Tops (polyester and wool)		
Weight	Linear Density	ASTM D-861
Color Measurement	*	--
Single Filament Properties	Linear Density	ASTM D-1577
Breaking Strength Filament	Man-Made Fibers from Filament to Tow	ASTM D-2101
Blended and Dyed Tops		
Weight	Linear Density	ASTM D-861
Color Measurement	*	--
Yarns Produced from Blended Tops		
Fiber Content	Wool Content	F.S. 2101
Polyester Identification	**	--
Yarn Count	Twist in Singles Yarn	ASTM D-1422 F.S. 4052
Yarn Twist	Twist in Ply Yarn	ASTM D-1423 F.S. 4054
Abrasion of Knit Fabric	Flat Abrasion	AATCC 119-1970
Color of Knit Fabric	*	
Fabrics		
Yarns/inch	Structure of Woven Fabric	ASTM D-1910 F.S. 5050
Weight	Structure of Woven Fabric	F.S. 5041

TABLE 6 Continued.

Property	Title	Test Method ASTM, AATCC, Federal Standard 191-
Thickness	Thickness of Textile Fabric	ASTM D-1777 F.S. 5030
Permeability	Air Permeability	ASTM D-737 F.S. 5450.1
Bending Length	Stiffness of Fabric	ASTM D-1388 F.S. 5202
Drape		Ref. 19
Wrinkle Recovery	Monsanto Wrinkle Recovery	ASTM D-1295 F.S. 5212
Breaking Strength	Grab Method	ASTM D-1682 F.S. 5100
	Ravel Strip	F.S. 5104
Shrinkage	Relaxation of Wool Cloth	ASTM D-462 F.S. 5558
Pilling	Random Tumble Pilling	ASTM D-1375
Accelerated Abrasion	Impeller Tumble Test	AATCC 93-1970
Flex Abrasion	Stoll Flex Abrasion	ASTM D-1175 F.S. 5300
Frosting	Flat Abrasion	AATCC 119-1970
Dry Cleaning		F.S. 5622
Heat Setting	* * *	--
Crocking	Colorfastness to Crocking	AATCC 8 F.S. 5651
Light	Colorfastness to Light	AATCC 16 F.S. 5660
Perspiration	Colorfastness to Perspiration	AATCC 15 F.S. 5680

* Diano Automate

** Staining test to determine whether polyester fiber is cationic dyeable.

*** Special test as described in body of report

2. Analysis of Dyed and Blended Tops

The weights of the dyed and blended tops as prepared for the yarn spinner are shown in Table 10. Color measurements were made on hand-carded samples of the blended tops and the results are shown in Table 11. The tristimulus values were found to be essentially the same for all samples as was predicted from the color measurements made on the unblended tops.

TABLE 7

WEIGHT OF DYED TOPS USED IN MAKING BLENDED TOPS

Fiber	Weight (grains/yd.)
Dacron 35 (3.0 denier)	169
Dacron 54 (3.0 denier)	128
Dacron 54 (4.5 denier)	180
Dacron 64 (3.0 denier)	143
Wool 64s	168
Wool 64-70s	207

TABLE 8

COLOR MEASUREMENTS FOR DYED TOPS

Fiber	C.I.E. Tristimulus Values X	Y	Z
Dacron 35	.1078	.1072	.1525
Dacron 54	.1099	.1096	.1588
Dacron 54 (4.5)	.1026	.1025	.1457
Dacron 64	.1070	.1071	.1500
Wool 64s	.1091	.1084	.1552
Wool 64-70s	.1093	.1085	.1546

TABLE 9

SINGLE FILAMENT PROPERTIES OF DYED FIBERS

Fiber	Denier	C.V. %	Breaking Strength g/den.	C.V. %	Breaking Elongation %	C.V. %
Dacron 35 (3.0 denier)	3.22	11	3.31	10	25.1	29
Dacron 54 (3.0 denier)	3.00	12	4.35	14	28.1	37
Dacron 54 (4.5 denier)	4.93	12	4.20	14	36.0	28
Dacron 64 (3.0 denier)	3.30	10	3.10	9	21.9	29
Wool 64s	5.43	29	1.15	28	18.7	53
Wool 64-70s	5.64	25	0.93	20	15.4	71

TABLE 10

WEIGHTS OF DYED AND BLENDED TOPS

Blend Number	Weight (grains/yd.)
B-1	226
B-2	235
B-3	230
B-4	243
B-5	239
B-6	234
B-7	252
B-8	245
B-11	241
B-12	231

TABLE 11

COLOR MEASUREMENTS OF DYED AND BLENDED TOPS

Blend No.	C.I.E. Tristimulus Values X	Y	Z
B-1	.1070	.1072	.1480
B-2	.1073	.1083	.1493
B-3	.1051	.1052	.1467
B-4	.1046	.1042	.1461
B-5	.1069	.1063	.1491
B-6	.1067	.1058	.1492
B-7	.1044	.1040	.1449
B-8	.1061	.1056	.1483
B-11	.1023	.1020	.1442
B-12	.1044	.1040	.1437

3. Analysis of Yarns from Blended Top

a. Fiber Content

The twelve yarns produced by the yarn spinner were analyzed for fiber content. The results are shown in Table 12 along with the targeted values. For those yarns which were supposed to have sixty (60) per cent polyester, the analyses fell between 59.7 and 62.4 per cent. For those which were supposed to have forty (40) per cent polyester, the analyses fell between 40.2 and 41.5 per cent. Thus, it was concluded that the blending had been performed correctly.

TABLE 12

FIBER CONTENT OF YARNS

Yarn Designation	Polyester Component	Wool Component	Target Composition Polyester/Wool	Composition Found Polyester/Wool
Y-1	Dacron 64 (3)	64s	60/40	60.8/39.2
Y-2	Dacron 54 (3)	64s	40/60	41.5/58.5
Y-3	Dacron 64 (3)	64-70s	40/60	40.2/59.8
Y-4	Dacron 54 (3)	64-70s	60/40	61.3/38.7
Y-5	Dacron 64 (3)	64s	40/60	40.6/59.4
Y-6	Dacron 54 (3)	64s	60/40	62.4/37.6
Y-7	Dacron 64 (3)	64-70s	60/40	60.4/39.6
Y-8	Dacron 54 (3)	64-70s	40/60	40.5/59.5
Y-9	Dacron 54 (3)	64s	60/40	62.0/38.0
Y-10	Dacron 54 (3)	64s	60/40	61.8/38.2
Y-11	Dacron 54 (4.5)	64s	60/40	62.4/37.6
Y-12	Dacron 35 (3)	64s	60/40	59.7/40.3
Std. 1*	-	-	-	58.0/42.0

*Air Force Tropical Standard No. 1

b. Identification of Polyester Type

The fact that Dacron 64 is made from a polymer which is chemically different from that used in making Dacron 54 and Dacron 35 was the basis of a dyeing test to determine whether the blends had been made properly. The wool component of the blends was first removed by treating the yarn with an aqueous solution of sodium hypochlorite (5.0 per cent solution) followed by a treatment with sodium bisulfite (aqueous). The dye was then removed from the remaining polyester fiber by Soxhlet extraction with perchloroethylene. The polyester fibers were then dyed with a cationic dye (Sevron Blue 2G, C.I. Basic Blue 22) at 100°C for one hour (pH 4.5). The only samples which dyed were those samples containing Dacron 64, namely Y-1, Y-3, Y-5, and Y-7 as would be predicted if no mistakes had been made in the processing of the dyed tops to yarn. Dacron 64 is referred to as a cationic dyeable polyester fiber. Dacron 54 and Dacron 35 are not dyeable with cationic dyes.

c. Yarn Count

The yarn count for a standard worsted fabric, Type III, Class 1, is 40's, two-ply (worsted system) which corresponds to an equivalent singles worsted count of 20. With the exception of yarn, Y-5, the yarn counts were found to lie between 18.7 and 20.6 equivalent singles worsted count (Table 13). The low value of 15.7 for yarn Y-5 was due to a mistake that was made by the yarn spinner.

d. Yarn Twist

The measured values for the yarn twist in both the singles and ply yarns, along with the target twist are shown in Table 13. It should be noted that the ply twist is somewhat higher than the twist in the singles yarn. This is standard practice for plied worsted yarns.

TABLE 13

WORSTED COUNT AND TWIST OF YARNS

Yarn Designations	Worsted Count Equivalent Singles	Yarn Twist Target	Twist Found	
			Singles	Ply
Y-1	18.9	12	11.4	14.0
Y-2	19.7	12	11.0	13.2
Y-3	19.6	15	13.8	15.8
Y-4	19.5	15	13.8	15.4
Y-5	15.7*	15	13.7	16.0
Y-6	19.8	15	14.1	15.9
Y-7	19.3	12	11.5	12.8
Y-8	20.6	12	11.2	13.4
Y-9	18.7	12	11.5	13.2
Y-10	20.1	18	16.7	19.9
Y-11	20.1	15	13.8	15.6
Y-12	20.1	15	13.9	15.7
Air Force Tropical Standard No. 1	20.0	-	10.6	10.8

*Mistakenly made 32's singles instead of 40's singles

e. Abrasion of Yarns in the Form of Knitted Fabrics

To obtain some information on abrasion, the yarns were knitted in the form of a sleeve on the Lawson Hemphill Knitter Analyzer. The knitted fabrics were abraded using the wire-screen, flat abrasion test(1). Each sample was abraded 10,000 and 12,000 cycles and examined for change in appearance. Two features of the abraded fabrics were noted, namely, pilling and frosting. Pilling predominated because the yarns were in a knit structure and the movement of the yarns during abrasion was greater than it would be in a tightly woven structure. From the results of the abrasion tests, it was concluded that the effects of the variables in fabric construction and composition on abrasion could be determined from abrasion tests on the woven fabrics. Several conclusions were reached from this preliminary test. The effect of the wool grade was small. Fabrics containing Dacron 54 pilled much worse than fabrics containing Dacron 64, whereas fabrics containing Dacron 64 exhibited more frosting. An increase in yarn twist decreased the tendency to pill as would be expected.

f. Color

Color measurements of the knitted fabrics, unabraded, are shown in Table 14. Color difference calculations were made using the average of the tristimulus values of all twelve samples as a reference. This was done to assess the variability in shade among the samples. With the exception of sample Y-11, color differences were less than 1.0 N.B.S. unit, which is a commercially acceptable color match. Sample Y-11 contains the Dacron 54 (4.5 denier) and the larger color difference value is attributed to the larger denier of the fiber.

TABLE 14

COLOR MEASUREMENTS ON KNIT FABRICS

Designation	Tristimulus Values X	Y	Z	Color Difference of Fabric and Reference* N.B.S. Units**
Y-1	.0342	.0328	.0625	0.67
Y-2	.0357	.0338	.0649	0.23
Y-3	.0341	.0325	.0603	0.90
Y-4	.0361	.0343	.0659	0.30
Y-5	.0339	.0325	.0612	0.79
Y-6	.0345	.0325	.0627	0.52
Y-7	.0348	.0330	.0638	0.33
Y-8	.0366	.0348	.0662	0.41
Y-9	.0360	.0341	.0666	0.61
Y-10	.0363	.0344	.0680	0.92
Y-11	.0360	.0339	.0683	1.36
Y-12	.0367	.0350	.0679	0.69
Reference*	.0354	.0336	.0642	--

*Hypothetical fabric--Tristimulus values are average of all tristimulus values for all 12 fabrics.

**1 N.B.S. Unit difference defined as the limit for commercially acceptable color match

4. Analysis of Experimental Fabrics

a. Fabric Construction

The construction and weight of each of the experimental fabrics were determined as shown in Table 15. The number of yarn ends per inch (warp ends) varied between 55 and 58 compared with 55 ends per inch in the Air Force Standard Fabric No. 1. The number of yarn picks per inch (filling) varied between 42 and 45 compared with 45 picks per inch for the Air Force Standard Fabric No. 1.

b. Fabric Weight

The fabric weights (oz/yd.^{2}) for the experimental fabrics were between 5.6 and 6.3 with the exception of fabric F-5 which had a weight of 7.5 oz/yd.^{2} due to a mistake in spinning the yarn from which this fabric was made (Table 15). The fabric weights obtained compare favorably with the value for the Air Force Tropical Standard Fabric No. 1, namely 5.8 oz/yd.^{2}.

TABLE 15

FABRIC CONSTRUCTION AND WEIGHT

Fabric Designation	Ends/inch	Picks/inch	Fabric Weight oz/yd^2
F-1	57	42	6.0
F-2	57	42	6.0
F-3	57	42	6.2
F-4	56	42	6.0
F-5	56	43	7.5
F-6	56	44	6.3
F-7	57	44	6.0
F-8	56	42	5.8
F-9	58	45	6.0
F-10	56	42	6.3
F-11	55	43	5.6
F-12	55	43	6.0
Std. 1*	55	45	5.8

* Air Force Standard Fabric No. 1

c. Fabric Thickness

With the exception of fabric F-5, the values for the fabric thickness fell between 0.016 and 0.018 inches compared with 0.015 inches for the Air Force Tropical Standard Fabric No. 1 (Table 16) Fabric F-5 had a greater thickness (0.023 inches) due to the heavier yarn used in its construction.

d. Air Permeability

The experimental fabrics exhibited a wide range in air permeability values, from 38 $ft^3/min./ft^2$ to 120 $ft^3/min/ft^2$ as shown in Table 17. The air permeability for the Air Force Tropical Standard Fabric No. 1 was 39 $ft^3/min/ft^2$. With respect to the variables being studied, it was concluded that an increase in yarn twist results in an increase in air permeability. Fabrics containing Dacron 54 (3.0 denier) have slightly higher permeability than those containing Dacron 64 (3.0 denier) and the 60/40 polyester/wool fabrics had a higher permeability than the 40/60 polyester/wool fabrics. A statistical analysis of the data was performed after normalizing the data with respect to fabric weight (Table 18). It was clear from the analysis that the type Dacron and blend level were important factors affecting the air permeability.

The conclusions drawn from the analysis of variance (Table 18) are as follows:

Variable	Level of Significance	Comments
Blend level	0.99	1. 60/40 polyester/ wool more permeable than 40/60
Type polyester	0.99	1. Dacron 54 fabrics more permeable than Dacron 64 fabrics
Grade of Wool	0.95	1. Wool 64-70s fabrics more permeable than wool 64s fabrics.

TABLE 16

FABRIC THICKNESS

Fabric Designation	Inches	Fabric Designation	Inches
F-1	0.017	F-7	0.018
F-2	0.016	F-8	0.017
F-3	0.016	F-9	0.018
F-4	0.023	F-10	0.017
F-5	0.018	F-11	0.016
F-6		F-12	0.016
		Std. No. 1*	0.015

*Air Force Tropical Standard No. 1

TABLE 17

AIR PERMEABILITY OF FABRICS

Fabric Designation	$ft^3/min/ft^2$	Fabric Designation	$ft^3/min/ft^2$
F-1	55	F-9	42
F-2	41	F-10	120
F-3	39	F-11	91
F-4	64	F-12	73
F-5	38	Std. 1*	39
F-6	69	Std. 2*	41
F-7	51	Std. 3*	38
F-8	61		

*Air Force Tropical Standards

TABLE 18

AIR PERMEABILITY - FRACTIONAL
FACTORIAL ANALYSIS OF VARIANCE

F Values Found ($V_1 = 1$, $V_2 = 36$)

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
42.31	46.63				.55
23.90		4.49			6.47
19.54			1.37		1.04
42.31				.55	46.63
	24.46	4.16			1.18
	26.06		1.66		6.42
	46.63			.55	42.31
		2.56	.89		.16
		2.51		.17	.94
			.94	.17	2.51

e. Bending Length

The bending lengths for the experimental fabrics are shown in Table 19. The bending lengths in the filling direction are generally lower than in the warp direction as would be predicted from the fabric construction (warp and filling yarns per inch). All of the values are about the same as those for the Air Force Tropical Standard No. 1. The bending length values were normalized with respect to fabric thickness and fabric weight as follows:

$G_o = c^3 w/t^3$ where

G_o = flexural rigidity

c = bending length

t = fabric thickness

w = weight of fabric

The values for G_o obtained were analyzed statistically (Table 20) and summarized below:

TABLE 19

BENDING LENGTH (CM.)

Yarn Designation	Warp	Filling
F-1	2.16	1.90
F-2	2.07	1.86
F-3	1.98	1.81
F-4	2.11	1.90
F-5	2.23	2.17
F-6	2.17	2.01
F-7	2.06	1.89
F-8	2.16	2.03
F-9	2.13	2.08
F-10	2.29	1.91
F-11	2.31	2.09
F-12	2.24	2.05
Std. No. 1*	2.22	2.04

*Air Force Tropical Standard No. 1

TABLE 20

BENDING LENGTH - FRACTIONAL FACTORIAL
ANALYSIS OF VARIANCE

F Values Found ($V_1 = 1$, $V_2 = 36$)

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
			Filling		
5.24	30.27				1.55
2.89		.51			.99
3.48			4.96		4.12
5.24				1.55	30.27
	30.46	.94			6.26
	32.36		7.97		1.77
	30.27			1.55	5.24
		.53	4.25		.88
		.53		.88	4.25
			4.25	.88	.53
			Warp		
3.06	1.48				1.73
2.96		1.33			.62
9.15			80.14		1.28
3.06				1.73	1.48
	1.37	1.27			.40
	3.97		71.95		1.71
	1.48			1.73	3.06
		3.99	77.71		5.03
		3.99		5.03	77.71
			77.71	5.03	3.99

Bending Length - Filling Direction

Variable	Level of Significance	Comments
Blend level	0.95	1. 40/60 polyester/wool fabrics have lower bending length than 60/40 polyester/wool fabrics
Type of polyester	0.99	2. Dacron 54 fabrics have lower bending length than Dacron 64 fabrics
Carbonizing	0.95	3. Carbonized fabrics have lower bending length than uncarbonized fabrics.

Bending Length - Warp Direction

Variable	Level of Significance	Comments
Carbonizing	0.99	1. Carbonized fabrics lower bending length than uncarbonized fabrics.

f. Fabric Drape

The drape of the fabrics was determined by measuring the area of the shadow cast by a circular piece of fabric ten inches in diameter when placed on circular pedestals having diameters of four, five and six inches(19). The drape coefficient is the ratio of the area of the shadow cast by the fabric to the area of the fabric. The results are shown in Table 21. The effects of the variables being studied on fabric drape are not obvious from an inspection of these data probably because of the differences in the weight and thickness of the fabrics. The drape of all the experimental fabrics was judged to be equal to or better than that of the Air Force tropical standards.

TABLE 21

FABRIC DRAPE

Fabric Designation	4 inch.	5 inch.	6 inch.
F-1	0.41	0.52	0.65
F-2	0.36	0.50	0.56
F-3	0.35	0.43	0.52
F-4	0.42	0.51	0.67
F-5	0.46	0.57	0.69
F-6	0.45	0.46	0.48
F-7	0.41	0.51	0.64
F-8	0.42	0.49	0.66
F-9	0.43	0.54	0.71
F-10	0.41	0.42	0.65
F-11	0.42	0.49	0.59
F-12	0.37	0.52	0.61
Std. 2*	0.45	0.62	0.77
Std. 3*	0.54	0.65	0.73

*Air Force Tropical Standards
Std. 2 - 9.0 oz.
Std. 3 - 10.0 oz.

g. Wrinkle Recovery

Only small differences in the wrinkle recovery values of the twelve fabrics were noted as shown in Table 22. They were found to be comparable to the values for the Air Force Standard fabric. An unexpected finding was that those fabrics having a composition of 40/60 polyester/wool had a slightly better wrinkle recovery than those having a composition of 60/40 polyester/wool.

TABLE 22

WRINKLE RECOVERY (MONSANTO)

Fabric Designation	Warp	Filling
F-1	83	85
F-2	87	87
F-3	86	86
F-4	89	81
F-5	87	87
F-6	86	85
F-7	88	83
F-8	91	86
F-9	88	84
F-10	92	86
F-11	87	85
F-12	88	86
Std. No. 1*	94	87

*Air Force Tropical Standard No. 1

h. Breaking Strength

Two methods for determining breaking strength were used, the ravel strip method and the grab method. The results are shown in Table 23. Both methods revealed that fabrics containing Dacron 54 (3.0 and 4.5 denier) are much stronger than those containing Dacron 64 or Dacron 35. The fabric containing Dacron 35 was somewhat stronger than fabrics containing Dacron 64. It was also noted that the breaking strength is greater for fabrics having a composition, 60/40 polyester/wool than for fabrics having a composition, 40/60 polyester/wool. These observations were confirmed in a statistical analysis of the data as shown in Table 24. The results are summarized below:

Breaking Strength

Variable	Level of Significance	Comments
Blend level	0.99*	1. 60/40 polyester/wool fabrics have higher breaking strength than 40/60 polyester/wool fabrics.
Type polyester	0.99*	2. Dacron 54 fabrics have higher breaking strength than Dacron 64 fabrics.

*For both grab and ravel strip tests in both filling and warp directions

TABLE 23

BREAKING STRENGTH

Fabric Designation	Grab (lb) Warp	Grab (lb) Filling	Ravel Strip (lb/in) Warp	Ravel Strip (lb/in) Filling
F-1	134	97	84	61
F-2	173	119	94	69
F-3	117	81	68	50
F-4	175	138	110	87
F-5	154	106	87	66
F-6	196	156	127	97
F-7	131	102	83	65
F-8	168	108	96	72
F-9	211	157	126	101
F-10	206	146	124	94
F-11	201	148	119	93
F-12	159	122	101	77
Std. No.1*	-	-	109	-

*Air Force Tropical Standard No. 1

TABLE 24

BREAKING STRENGTH - FRACTIONAL FACTORIAL
ANALYSIS OF VARIANCE

F Values Found ($V_1 = 1$, $V_2 = 36$)

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
			Grab-Filling		
100.30	287.71				5.32
11.16		.49			.07
11.16			.29		.32
100.30				5.32	287.71
	79.34	1.08			.91
	74.86		.69		.16
	287.71			5.32	100.30
		.39	.23		.46
		.39		.46	.23
			.23	.46	.39
			Grab--Warp		
21.24	530.89				2.53
1.36		.44			.02
1.36			.34		.01
21.24				2.53	530.89
	362.36	4.73			.06
	353.12		3.55		.20
	530.89			2.53	21.24
		.43	.33		.16
		143		.16	.33
			.33	.16	.43

TABLE 24 Continued

Ravel Strip--Filling

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
188.69	479.46				5.93
13.04		.00			.04
13.53			1.39		.00
188.69				5.93	479.46
	74.85	.00			.00
	81.93		3.31		.10
	479.46			5.93	188.69
		.00	1.02		.31
		.00		.31	1.02
			1.02	.31	.00

Ravel Strip--Warp

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
138.16	412.50				.82
11.29		.28			.42
11.31			.78		.02
138.16				.82	412.50
	86.77	.73			.04
	92.63		2.13		1.16
	412.50			.82	138.16
		.22	.60		.05
		.22		.05	.60
			.60	.05	.22

i. Fabric Shrinkage (Wool Cloth)

All of the experimental fabrics exhibited low shrinkage, well within the maximum allowable for Type III, Class 1 polyester/wool tropical worsted fabrics as defined in MIL-C-21115G, namely 2.5 and 2.0% for warp and filling directions, respectively. Shrinkage data are shown in Table 25.

TABLE 25

FABRIC SHRINKAGE

Fabric Designation	% Shrinkage Warp	% Shrinkage Filling
F-1	0.46	0.03
F-2	1.15	0.92
F-3	1.60	1.15
F-4	0.81	0.34
F-5	1.30	1.50
F-6	0.92	0.46
F-7	0.80	0.22
F-8	1.15	0.92
F-9	1.03	0.46
F-10	1.74	1.16
F-11	0.92	0.57
F-12	0.92	0.22
Std. No. 3	1.15	0.00

*Air Force Tropical Standard

j. Random Tumble Pilling

Random tumble pilling tests were made on both singed and unsinged fabrics (duration of test - 30 min. and 60 min.). The pilling ratings are recorded in Table 26. Inspection of the data for the unsinged fabrics shows that the pilling of fabrics containing Dacron 54 is worse than the pilling of fabrics containing Dacron 64. The pilling of fabrics containing Dacron 64 is less for the 60 min. test than for the 30 min. test whereas the pilling of fabrics containing Dacron 54 is greater for the 60 min. test than for the 30 min. test. This was an expected result since a "pill-resistant" fiber such as Dacron 64 does not exhibit high pilling because the pills once formed are easily removed due to the weakness of the fiber holding the pill to the fabric. Thus the pill is

TABLE 26

RANDOM TUMBLE PILLING TEST

Fabric Designation	Rating: Not Singed 30 Min.	60 Min.	Singed 30 Min.	60 Min.
F-1	3.5	4.0	4.0	4.0
F-2	3.5	3.0	4.5	4.0
F-3	4.5	5.0	4.0	4.0
F-4	3.5	2.5	4.5	3.0
F-5	5.0	5.0	4.5	4.5
F-6	3.5	2.5	4.5	4.0
F-7	3.5	4.0	4.0	4.0
F-8	4.0	3.0	4.0	4.0
F-9	3.5	2.5	4.0	3.0
F-10	3.5	3.0	4.0	4.0
F-11	4.0	3.5	4.5	4.5
F-12	3.5	4.5	4.5	4.5
Std. No. 1*			4.5**	4.0**
Std. No. 2*			4.0**	4.0**

* Tropical Standards

** Assumed to be singed

easily removed on abrasion. Fabrics containing Dacron 54, will also pill but because of the higher strength of the fibers holding the pills to the fabric, the pills are more diifıcult to remove.

The results pointed to the necessity for singeing in order to reduce pilling. The data for the singed fabrics are also shown in Table 26. The effect of singeing was very small for fabrics containing Dacron 64 whereas there was a pronounced improvement in pilling for fabrics containing Dacron 54. For the singed fabrics, no difference in pilling between fabrics containing Dacron 54 and Dacron 64 was noted. The singed fabrics containing Dacron 54 (4.5 denier) and Dacron 35 were slightly better than fabrics containing Dacron 54 (3.0 denier) and equal to the Air Force Tropical Standard fabrics No. 1 and No. 2. Statistical analyses of the pilling data confirm the above observations as shown in Table 27. In these analyses, there was an additional finding, namely, that for the unsinged fabrics, the pilling was greater for fabrics containing ~ 60 per cent polyester than for fabrics containing ~ 40 per cent polyester. A summary of the results of the statistical analysis follows:

Not-Singed Fabrics

Variable	Level of Significance	Comments
Type polyester	0.95	1. Dacron 64 fabrics show less pilling than Dacron 54 fabrics
Blend Level	0.95	2. 40/60 polyester/wool fabrics show less pilling than 60/40 polyester/wool fabrics

Singed Fabrics

No variable studied had a significant effect on pilling.

TABLE 27

RANDOM TUMBLE PILLING TEST - FRACTIONAL FACTORIAL ANALYSIS OF VARIANCE

F Values found ($V_1 = 1$, $V_2 = 4$)

Not Singed-30 Minutes

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
18.00	8.00				8.00
3.60		.00			.00
4.50			.50		.50
18.00				8.00	8.00
	1.14	.00			.00
	1.14		0.29		18.00
	8.00			8.00	1.25
		.00		1.14	.29
			.29	1.14	.00

Not Singed-60 Minutes

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
∞	∞				∞
.72		.00			.00
.72			.00		.00
∞				∞	∞
	19.6	.00			.00
	19.6		.00		.00
	∞			∞	∞
		.00	.00		.07
		.00		.07	.00
			.00	.07	.00

TABLE 27 Continued

Singed-30 Minutes

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
.00	2.00				2.00
.00		2.00			2.00
.00			.00		.00
.00				2.00	2.00
	2.00	2.00			.00
	2.00		.00		2.00
	2.00			2.00	.00
		2.00	.00		2.00
		2.00		2.00	.00
			.00	2.00	2.00

Singed-60 Minutes

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
1.80	1.80				.20
1.80		1.80			.20
1.80			1.80		.20
1.80				.20	1.80
	1.80	1.80			.20
	1.80		1.80		.20
	1.80			.20	1.80
		1.80	1.80		.20
		1.80		.20	1.80
			1.80	.20	1.80

j. Impeller Tumble Test (Accelerotor Method)

In this method, the abrasion of the fabric results in a loss in the fabric weight. From the data in Table 28, it is concluded that the only factor which affects the weight loss is the fiber content, a somewhat greater loss in weight shown for fabrics containing 60 per cent wool. This was an expected result due to the fact that wool fibers have less strength than polyester fibers.

TABLE 28

IMPELLER TUMBLE TEST

Fabric Designation	Weight Loss%	Fabric Designation	Weight Loss%
F-1	3.9	F-7	3.7
F-2	4.4	F-8	4.1
F-3	4.5	F-9	2.6
F-4	2.4	F-10	2.6
F-5	4.1	F-11	2.9
F-6	3.6	F-12	3.1
		Std. No. 1*	4.3

*Air Force Tropical Standard No. 1

k. Stoll Flex Abrasion (Federal Test Method Standard 191-5300 and ASTM D-1175)

The mean values for the cycles to rupture by this method are shown in Table 29. The only obvious conclusion is that fabrics containing Dacron 54 are superior to those containing Dacron 64 indicative of the greater toughness of Dacron 54. The fabric containing Dacron 35 is intermediate.

TABLE 29

FLEX ABRASION

Fabric Designation	No. of Cycles to Break (Average) Warp	Filling
F-1	1557	2515
F-2	4085	3808
F-3	1510	1556
F-4	5296	5142
F-5	1191	1291
F-6	2737	2361
F-7	1110	1103
F-8	2722	2326
F-9	1510	2392
F-10	2355	2376
F-11	3305	2946
F-12	1546	1161

1. Flat Abrasion Frosting (AATCC-119-1970)

A considerable amont of work was devoted to an evaluation of the experimental fabrics with respect to color change due to flat abrasion. The standard AATCC method is the only method available and designed for the assessment of fabric frosting. This method employs a Stoll Universal Abrader with the flat abrasion attachment. The abradent is a standard stainless steel wire screen and the head load is 2.5 pounds. The procedure requires that the fabric specimen be abraded for 1200 cycles, after which the sample is rinsed in luke-warm water and dried. The degree of color change due to abrasion is determined by reference to the AATCC Geometric Grey Scale for assessing color change.

A sample of each fabric was abraded to 12,000 cycles. All fabrics exhibited appreciable color change due to frosting and it was difficult to assess the effect of the variables at this level of abrasion. When they were abraded for 5000 cycles, significant differences among the samples were noted. The Grey Scale ratings for the abraded samples are shown in Table 30. The samples were also examined microscopically at lower power (40x) to assess the nature of the abraded surfaces. All fabric surfaces appeared more hairy than the Air Force standard worsted fabric. It appeared that the fabrics either had not been sheared sufficiently during finishing or had not been singed.

Since the fabrics were known to have been sheared properly but had not been singed, 25 yards of each fabric were returned to the fabric were returned to the fabric finisher for singeing. All subsequent abrasion tests were made on the singed fabrics.

TABLE 30

FLAT ABRASION - FROSTING (5000 CYCLES)

Fabric Designation	Grey Scale Rating	Fabric Designation	Grey Scale Rating
F-1	3.24	F-7	2.75
F-2	3.50	F-8	4.00
F-3	3.25	F-9	4.00
F-4	4.50	F-10	4.50
F-5	2.75	F-11	4.50
F-6	3.75	F-12	3.00

In order to obtain the maximum amount of information about the experimental fabrics as well as the Air Force Standard fabrics, five different levels of abrasion were used, 1200, 2400, 4800, 7200, and 9600 cycles. The abraded fabrics were evaluated for color change by five (5) observers. The angle of viewing was 45° with respect to the fabric surface and the light source was a MacBeth daylight lamp. The experimental results (mean values for ratings) are shown in Table 31. In order to determine the reproducibility of the abrasion test, a second set of samples were abraded for 4800 cycles. Comparsion of the results obtained with the previous 4800 cycle test is also shown in Table 31. When the samples were abraded for 1200 cycles, no differences between samples and standard fabrics were noted. However, with increasing severity of the abrasion, the variable which is most significant in frosting is the type of polyester used. Dacron 54 containing fabrics showed significantly less frosting than Dacron 64 containing fabrics. The fabric containing 4.5 denier Dacron 54 (F-11) showed a noticeably less color change on abrasion than its control fabric (F-6) containing 3.0 denier Dacron 54. The fabric containing Dacron 35 showed a degree of frosting intermediate between that of Dacron 54 and Dacron 64. The two Air Force Tropical Standard fabrics differed in their degree of frosting, the Tropical Standard No. 1 showing less frosting than the Tropical Standard No. 2. The No. 1 Standard resembles the experimental fabrics containing Dacron 54 in its abrasion behavior, whereas the No. 2 Standard resembles the experimental fabrics containing Dacron 64.

TABLE 31

GREY SCALE RATINGS FOR FLAT-ABRASION TEST

Fabric Designation	Grey Scale Rating Cycles of Abrasion 1200	2400	4800	**	7200	9600
F-1	5.0	4.8	4.1	4.1	3.5	3.1
F-2	4.9	4.7	4.5	4.5	4.1	3.5
F-3	5.0	4.4	4.0	4.4	3.6	3.4
F-4	5.0	5.0	4.4	4.8	4.5	4.3
F-5	4.9	4.3	3.9	4.2	3.3	3.0
F-6	5.0	4.9	4.5	4.6	4.0	4.0
F-7	5.0	4.9	4.0	4.0	3.4	3.2
F-8	5.0	4.7	4.5	4.5	4.4	3.8
F-9	5.0	5.0	4.0	4.5	4.3	3.3
F-10	5.0	5.0	4.5	4.4	4.2	3.1
F-11	5.0	4.9	4.6	4.7	4.5	4.1
F-12	5.0	4.9	4.1	4.1	3.8	3.1
Std. No.1*				4.5		
Std. No.2	4.9	4.5	3.6	4.1	3.3	2.9

*Air Force Standard Tropical Fabrics

**Duplicate test

Staining tests performed on these two fabrics indicated that the polyester component of the No. 1 Standard is not cationic dyeable and therefore not chemically like Dacron 64 whereas the polyester component of the No. 2 Standard is cationic dyeable like Dacron 64. These results prove that, in the past, uniform fabrics have been made from fibers having a chemical composition corresponding to the poly (ehtyleneterephthalate) homopolymer as well as those corresponding to a chemically modified poly (ethyleneterephthalate) polymer. In the latter case, the kind of chemical modification is one which provides dye sites for the absorption of cationic dyes. This modified fiber is sold as a pill-resistant fiber.

It was difficult to evaluate the effects of the variables other than the type polyester from an inspection of average values for color change as determined visually. Therefore, a statistical analysis using the Grey Scale ratings was made. The statistical analysis confirmed the conclusion that the type of polyester used was the most important variable affecting the frosting behavior. At all levels of abrasion, the type polyester was the most important variable. The variable of blend level was important in abrasions up to 2400 cycles. The variable of wool grade was somewhat important at 7200 cycles of abrasion and the variable of twist appeared to be of importance at 9600 cycles. These results are recorded in Table 32 and summarized below:

Flat Abrasion Tests
(Grey Scale Ratings)

Cycles of Abrasion	Significant Variable	Level of Significance	Comments
1200 cycles	-	-	1. No variable studied had an affect on color change
2400 cycles	Blend level Type polyester	0.99	1. 60/40 polyester/wool fabrics showed less color change than 40/60 polyester/wool fabrics 2. Dacron 54 fabrics showed less color change than Dacron 64 fabrics
4800 cycles 7200 cycles	Type polyester Type polyester	0.99 0.99	1. Dacron 54 fabrics showed less color change than Dacron 64 fabrics
9600 cycles	Type polyester Yarn twist	0.99 0.90	1. Dacron 54 showed less color change than Dacron 64 fabrics 2. 15 t.p.i. yarns showed less color change than 12 t.p.i. yarns.

TABLE 32

FLAT ABRASION TEST - FRACTIONAL FACTORIAL
ANALYSIS OF VARIANCE (GREY SCALE RATINGS)

F Values Found ($V_1 = 1$, $V_2 = 36$)

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
			1200 Cycles		
2.00	.00				.00
2.25		2.25			2.25
2.00			.00		.00
2.00				.00	.00
	.00	2.00			.00
	.00		.00		2.00
	.00			.95	.42
		2.00	.00		.00
		2.00		.00	.00
			.00	.00	2.00
			2400 Cycles		
27.00	9.72				3.00
20.45		.87			.09
11.79			.07		.63
27.00				3.00	9.72
	5.40	.60			.07
	5.32		.07		.07
	4.19			.02	1.51
		.54	.06		1.51
		.54		1.51	.06
			.06	1.51	.54

TABLE 32. Continued

4800 Cycles

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
3.00	147.00				.33
.59		.07			.07
.60			.07		.60
3.00				.33	147.00
	136.86	.31			.31
	147.00		3.00		.33
	147.00			.33	3.00
		.07	.59		.07
		.07		.07	.59
			.59	.07	.07

7200 Cycles

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
2.95	30.64				4.41
1.90		2.73			.30
1.50			.02		.17
2.53				5.68	30.95
	25.33	2.81			.31
	25.83		.28		.28
	30.64			4.41	2.95
		2.45	.18		2.45
		2.45		2.45	.18
			.08	2.78	2.78

9600 Cycles

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
2.95	30.64				4.41
1.90		2.73			.30
1.50			.02		.17
2.53				5.68	30.95
	25.33	2.81			.31
	25.83		.28		.28
	30.64			4.41	2.95
		2.45	.18		2.45
		2.45		2.45	.18
			.08	2.78	2.78

In order to obtain a quantitive assessment of the color change due to abrasion, color measurements were made using the Diano LSCE instrument. Two methods were used. In one method, the tristimulus values were determined for the abraded sample and its unabraded reference sample using $BaSO_4$ as a reference. Due to the fact that the values obtained are very low by this method, a second method was used in which the abraded sample was placed in the reference port of the instrument and the unabraded sample was placed in the sample port. This method is preferred for the measurement of small color differences for dark samples similar to the Air Force fabric. The color change for each fabric due to abrasion was calculated and expressed in terms of the total color difference, ΔE, the hue difference ΔC and the lightness difference ΔL, the unit for each being the MacAdam color difference unit.

The color difference calculations also revealed whether the abraded sample was red-green or blue-yellow with respect to the unabraded sample. It is well known that there are several factors which contribute to the observed color differences. The difference in the depth of shade of the two fiber components is one factor. Another factor which cannot be ignored is the degree of penetration of the dye in each of two fiber components. In the case of the experimental fabrics both fiber components are penetrated by dye and, therefore, any color change observed on abrasion is not associated with poor dye penetration. With respect to the difference in depth of shade of the two fiber components, the wool component in the Dacron 64/wool blend fabrics is slightly lighter in shade than the Dacron 64 component. The reverse is true for the Dacron 54 (3.0 denier)/wool fabrics. Since the wool component is preferentially worn away on abrasion, it would be expected that the color change on abrasion for the Dacron 64/wool fabric would be less apparent than that for the Dacron 54/wool fabrics, assuming both polyester fibers had the same abrasion resistance. The reverse of this was found indicating that Dacron 64 is much less abrasion resistant than Dacron 54.

The results of color difference measurements made on the abraded experimental fabrics are shown in tabular form in Tables 33-35 and in graphical form in Figures 13-27. As was expected, the overall color difference ΔL gives the best agreement with the visual assessment of color change associated with frosting.

TABLE 33

TOTAL COLOR CHANGE (ΔE) DUE TO FLAT ABRASION

(Mac Adam Color Difference Units)

Fabric Designation	Cycles of Abrasion 1200	2400	4800	7200	9600
F-1	2.12	1.18	2.43	2.27	2.56
F-2	.51	2.04	1.68	1.68	3.22
F-3	.96	.49	1.68	2.26	2.13
F-4	1.59	1.67	1.57	1.49	1.01
F-5	2.53	2.00	3.61	3.83	3.19
F-6	1.28	2.13	.85	1.79	3.21
F-7	3.85	4.36	5.11	4.48	5.26
F-8	1.34	1.32	1.79	2.00	3.76
F-9	.75	.84	1.00	.71	1.93
F-10	2.73	1.03	1.87	2.31	3.95
F-11	1.60	1.00	1.18	.98	1.69
F-12	1.09	1.9	3.44	1.84	3.26

TABLE 34

TOTAL HUE CHANGE (ΔC) DUE TO FLAT ABRASION

(Mac Adam Color Difference Units)

Fabric Designation	Cycles of Abrasion 1200	2400	4800	7200	9600
F-1	2.12	1.17	1.85	1.44	1.09
F-2	.49	2.00	.89	.89	1.95
F-3	.85	.49	1.61	1.64	1.01
F-4	1.56	1.67	1.57	1.44	.93
F-5	2.53	1.96	3.26	1.99	1.72
F-6	1.15	2.11	.85	1.61	2.95
F-7	3.83	4.35	5.04	4.33	4.66
F-8	1.31	1.11	1.37	1.44	3.09
F-9	.73	.82	1.00	.59	.74
F-10	2.71	1.00	1.85	2.22	1.27
F-11	1.49	.99	1.16	.81	1.23
F-12	1.05	1.93	3.31	1.07	1.63

TABLE 35

TOTAL LIGHTNESS CHANGE (ΔL) DUE TO FLAT ABRASION

(Mac Adam Color Difference Units)

Fabric Designation	Cycles of Abrasion 1200	2400	4800	7200	9600
F-1	-.08	.19	1.58	1.76	2.31
F-2	.12	.37	1.43	1.43	2.57
F-3	-.45	.02	.48	1.56	1.87
F-4	-.29	-.05	.17	.37	.41
F-5	.08	.42	1.56	3.27	2.68
F-6	-.55	-.27	.09	.77	1.28
F-7	-.39	.19	.35	1.17	2.43
F-8	.31	.71	1.15	1.38	2.16
F-9	-.15	-.18	-.01	.40	1.79
F-10	-.33	-.20	.22	.64	3.74
F-11	-.60	-.17	.20	.56	1.15
F-12	-.30	.00	.94	1.51	2.82

It was further concluded that the color differences for abrasion up to 4800 cycles were due to changes in hue. However, at 7200 cycles the change in lightness predominates.

From the color measurements and the color difference values shown in Tables 33-35, it is seen that fabrics containing Dacron 64 frost faster than fabrics containing Dacron 54. The higher twist (18 t.p.i) and the larger polyester denier (4.5) frosted at a slower rate. Since it is difficult to obtain information other than degree and rate of color change from the color difference calculations, a statistical analysis of the data was made. From the analysis and a comparison of it with the analysis of the visual assessment of color change (Grey Scale), it was concluded that lightness differences (ΔL) best correlates with frosting whereas the total color differences (ΔE) and hue difference (ΔC) best describe the color changes for abrasion levels up to 4800 cycles.

With respect to the variables studies in the experimental fabrics and their effect on abrasion, the type polyester used is most important. The variables of blend level and carbonizing are also important but to a less extent than the type polyester. Fabrics containing 60 per cent polyester showed less change in color on abrasion than fabrics containing 40 per cent polyester.

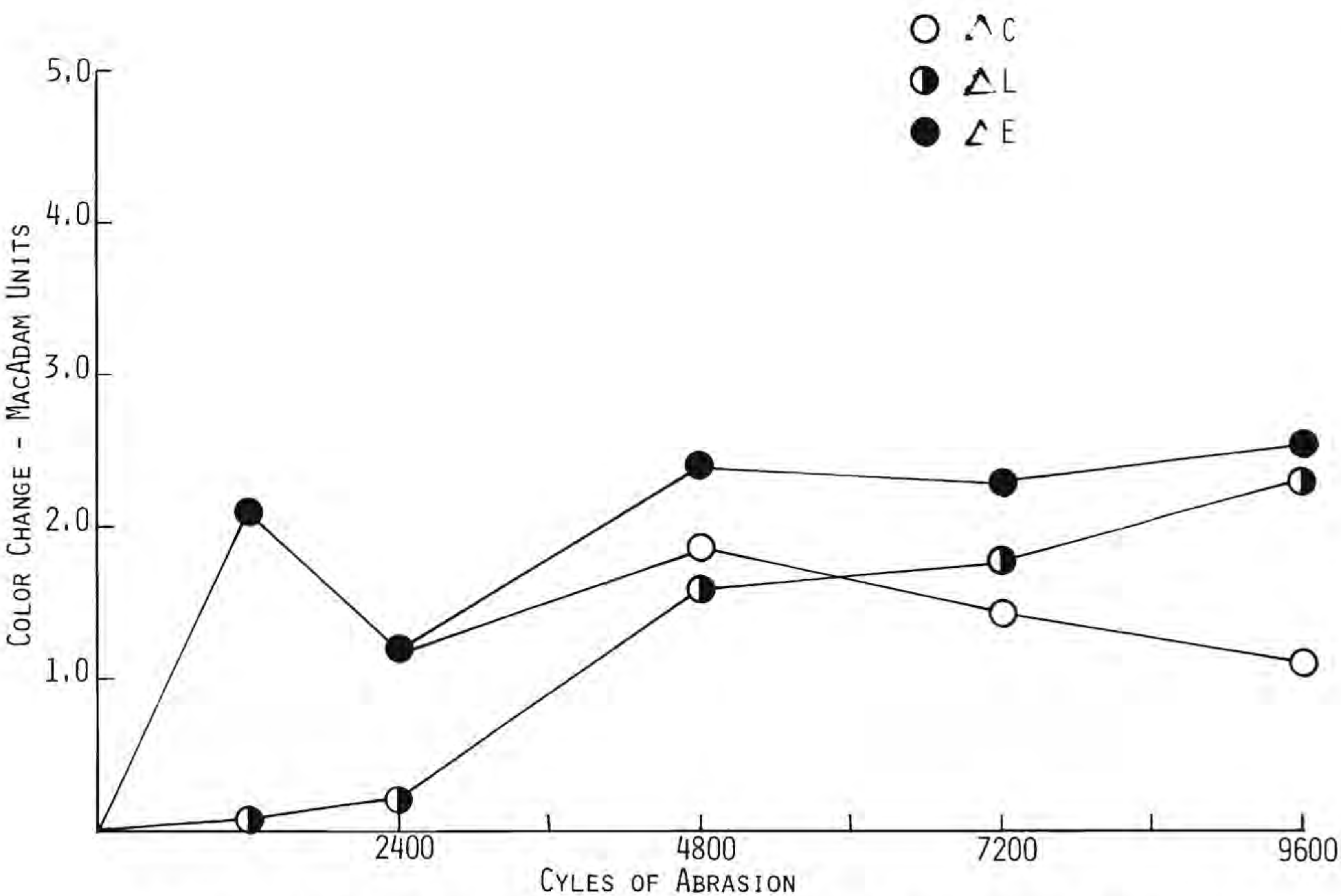

Figure 13. Color Changde Due to Flat Abrasion - Experimental Fabric F-1
(AATCC 119-1970)

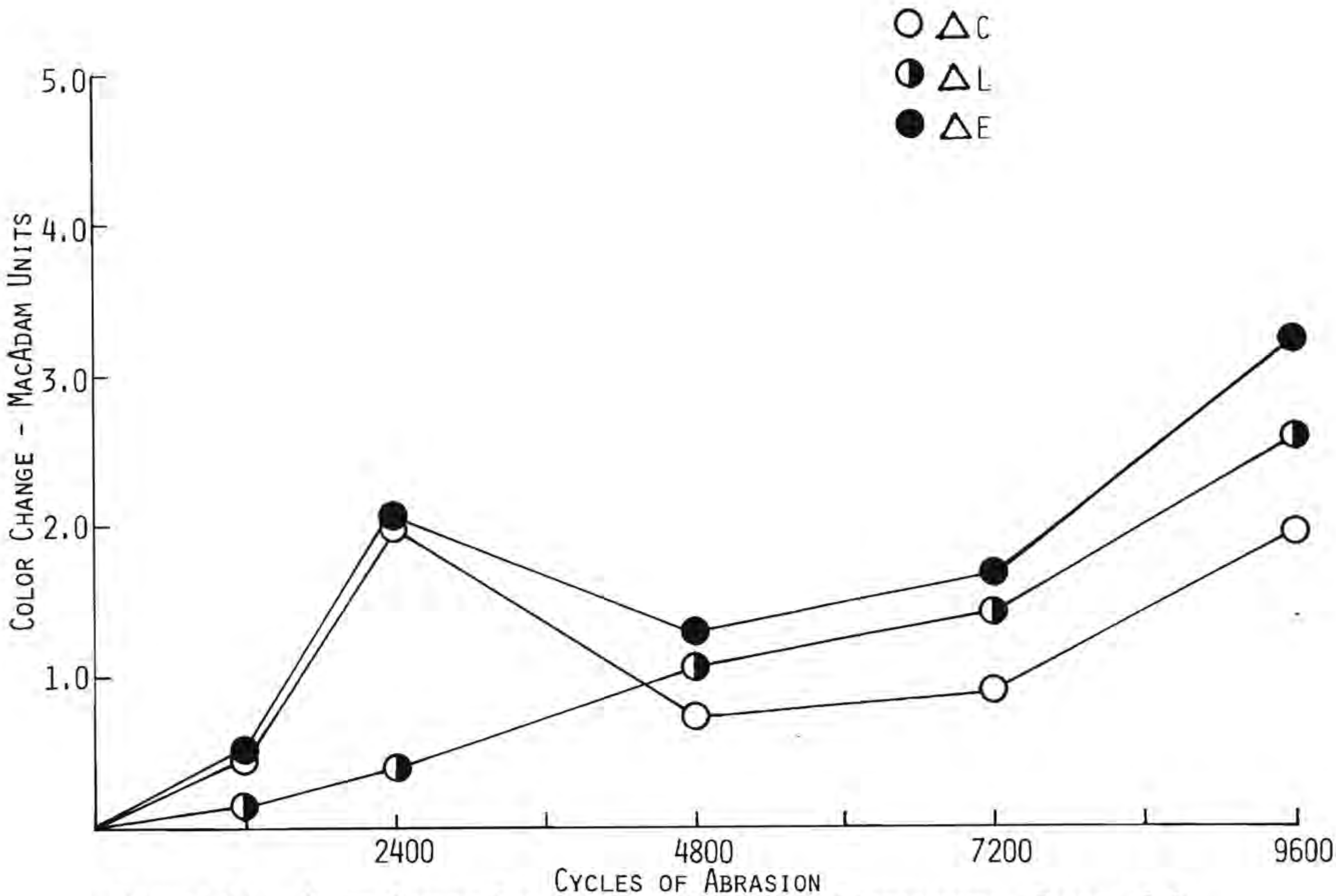

Figure 14. Color Change Due to Flat Abrasion - Experimental Fabric F-2 (AATCC-119-1970)

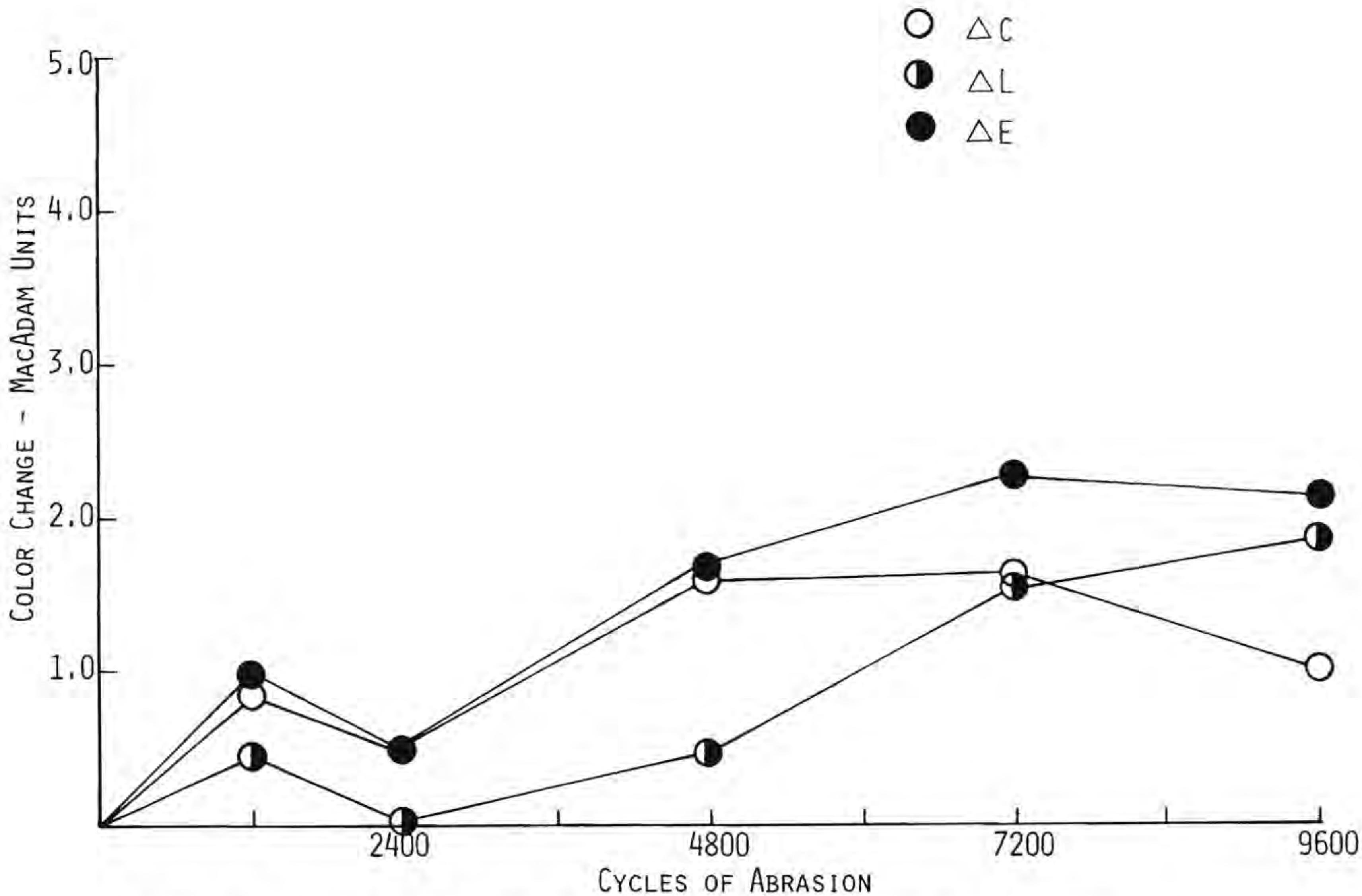

FIGURE 15. COLOR CHANGE DUE TO FLAT ABRASION - EXPERIMENTAL FABRIC F-3
(AATCC-119-1970)

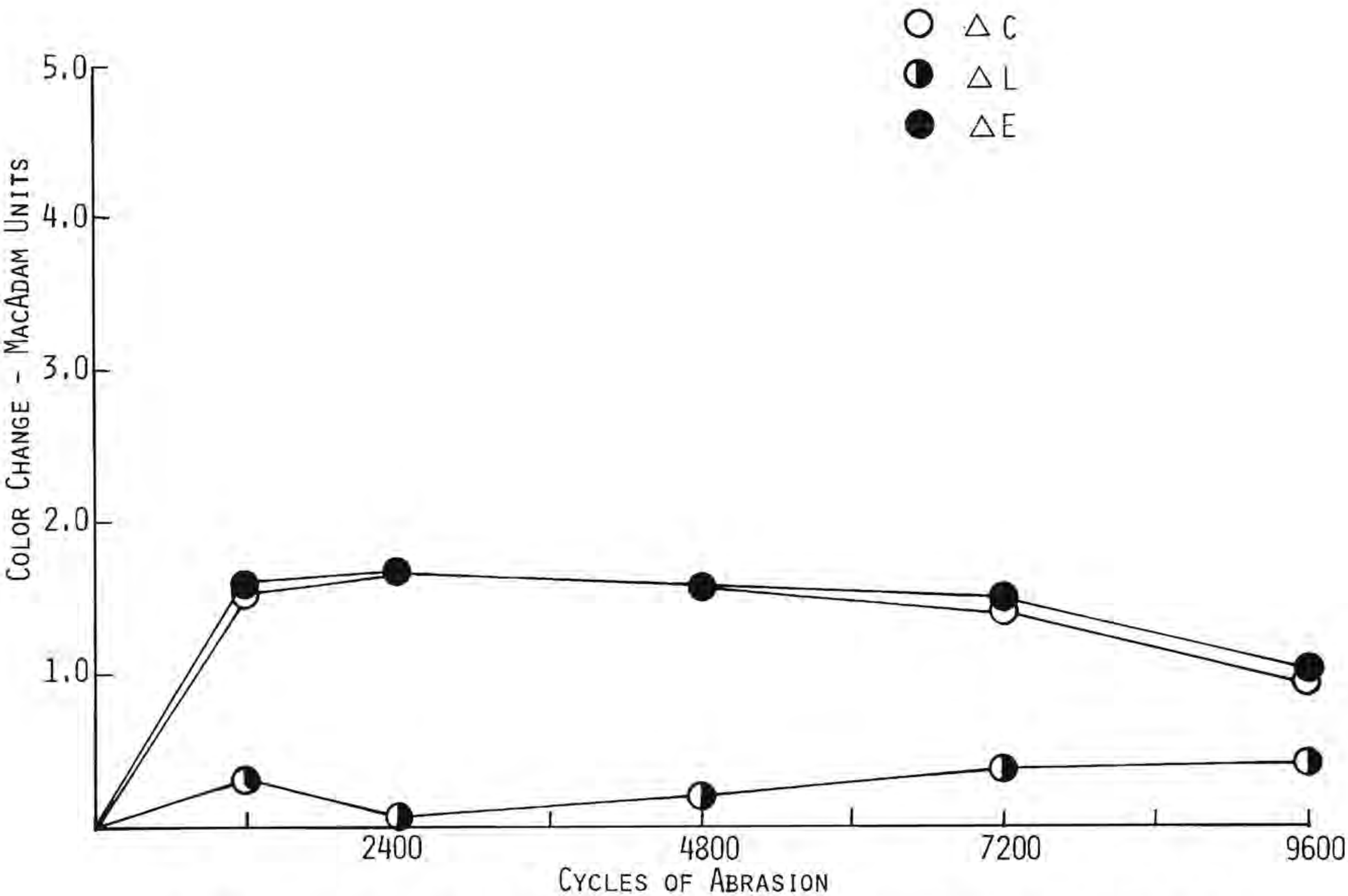

Figure 16. Color Change Due to Flat Abrasion - Experimental Fabric F-4
(AATCC-119-1970)

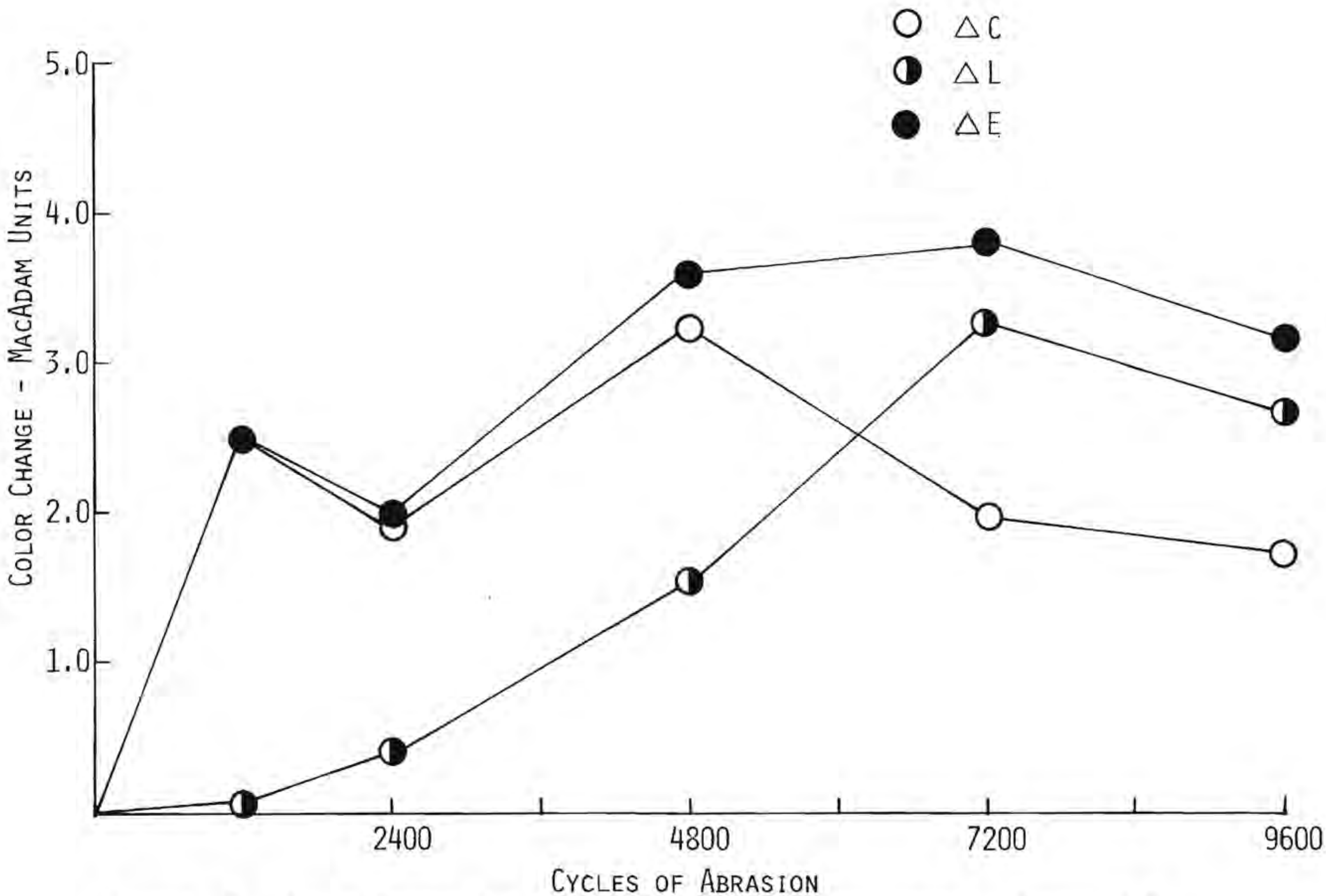

FIGURE 17. COLOR CHANGE DUE TO FLAT ABRASION - EXPERIMENTAL FABRIC F-5
(AATCC -119-1970)

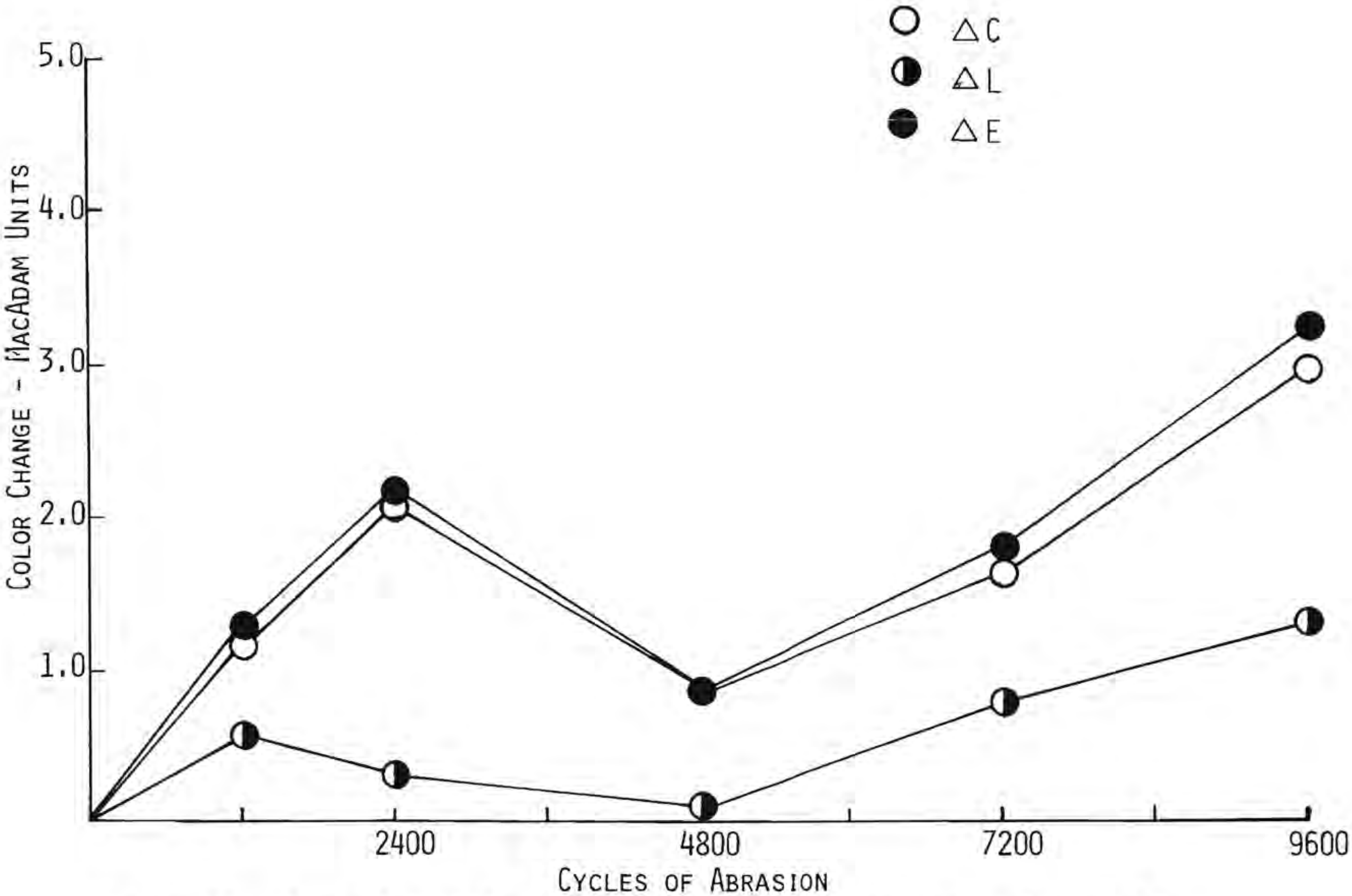

FIGURE 18. COLOR CHANGE DUE TO FLAT ABRASION - EXPERIMENTAL FABRIC F-6
(AATCC-119-1970)

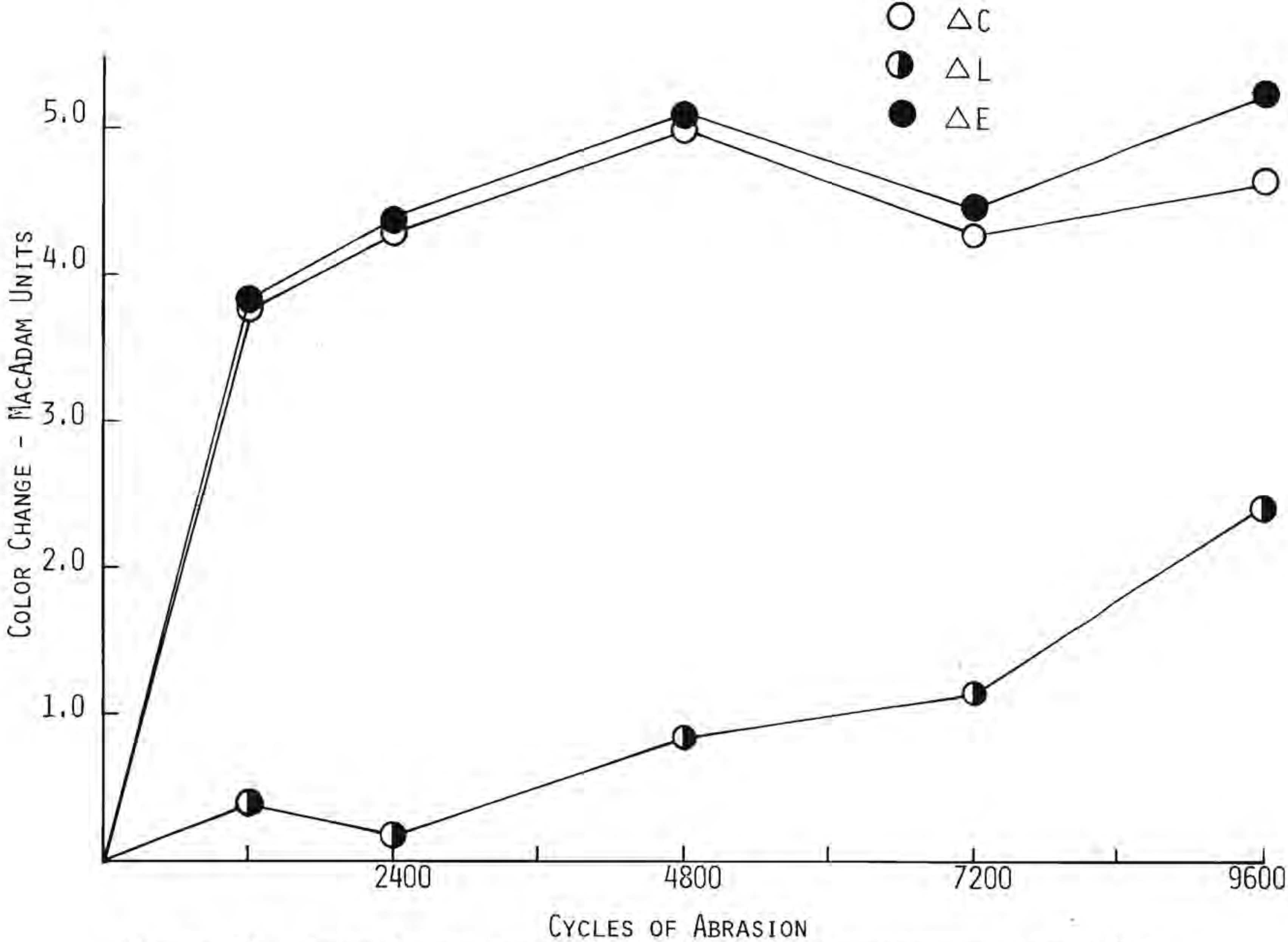

Figure 19. Color Change Due to Flat Abrasion - Experimental Fabric F-7 (AATCC-119-1970)

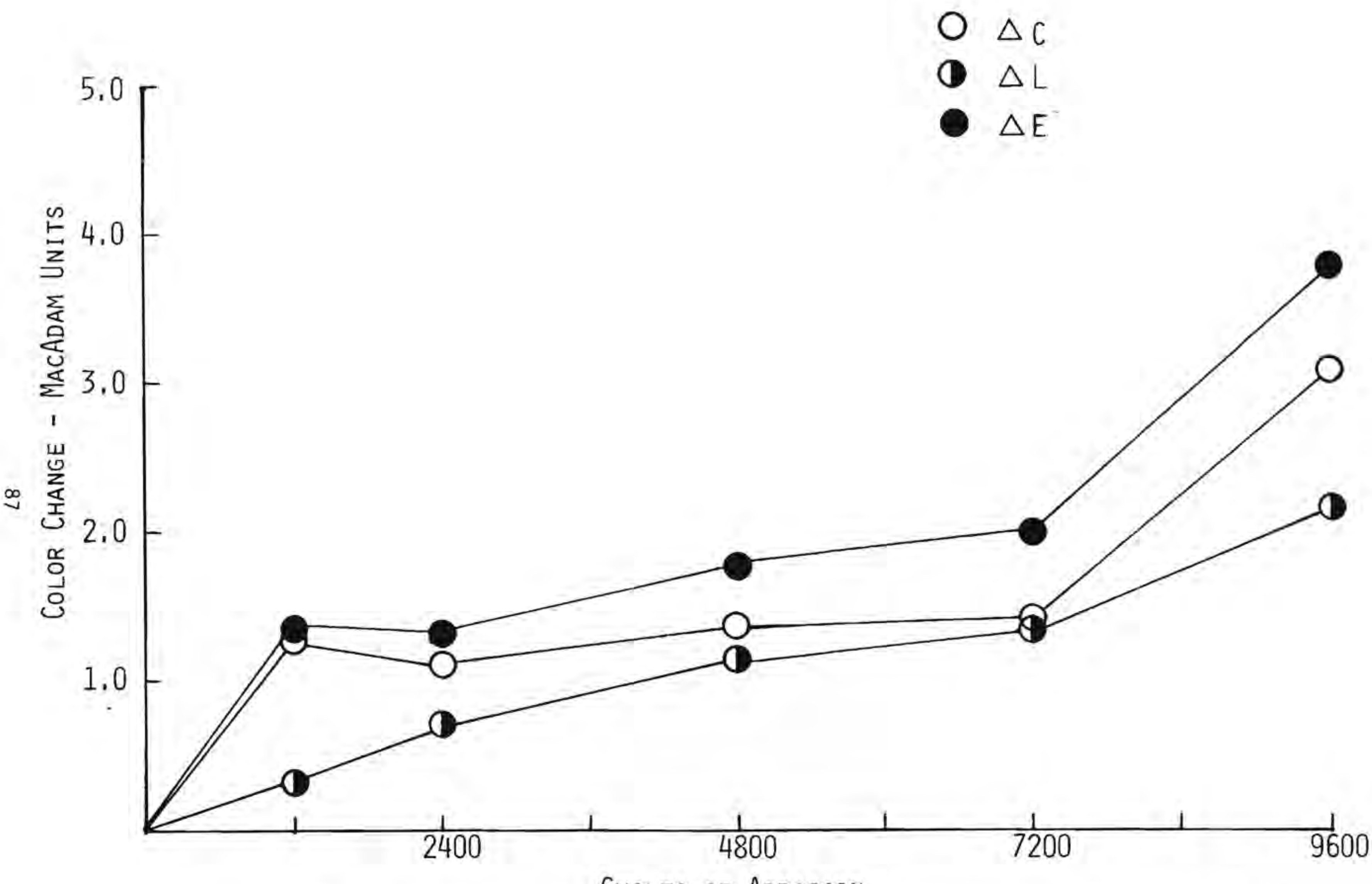

Figure 20. Color Change Due to Flat Abrasion - Experimental Fabric F-8
(AATCC-119-1970)

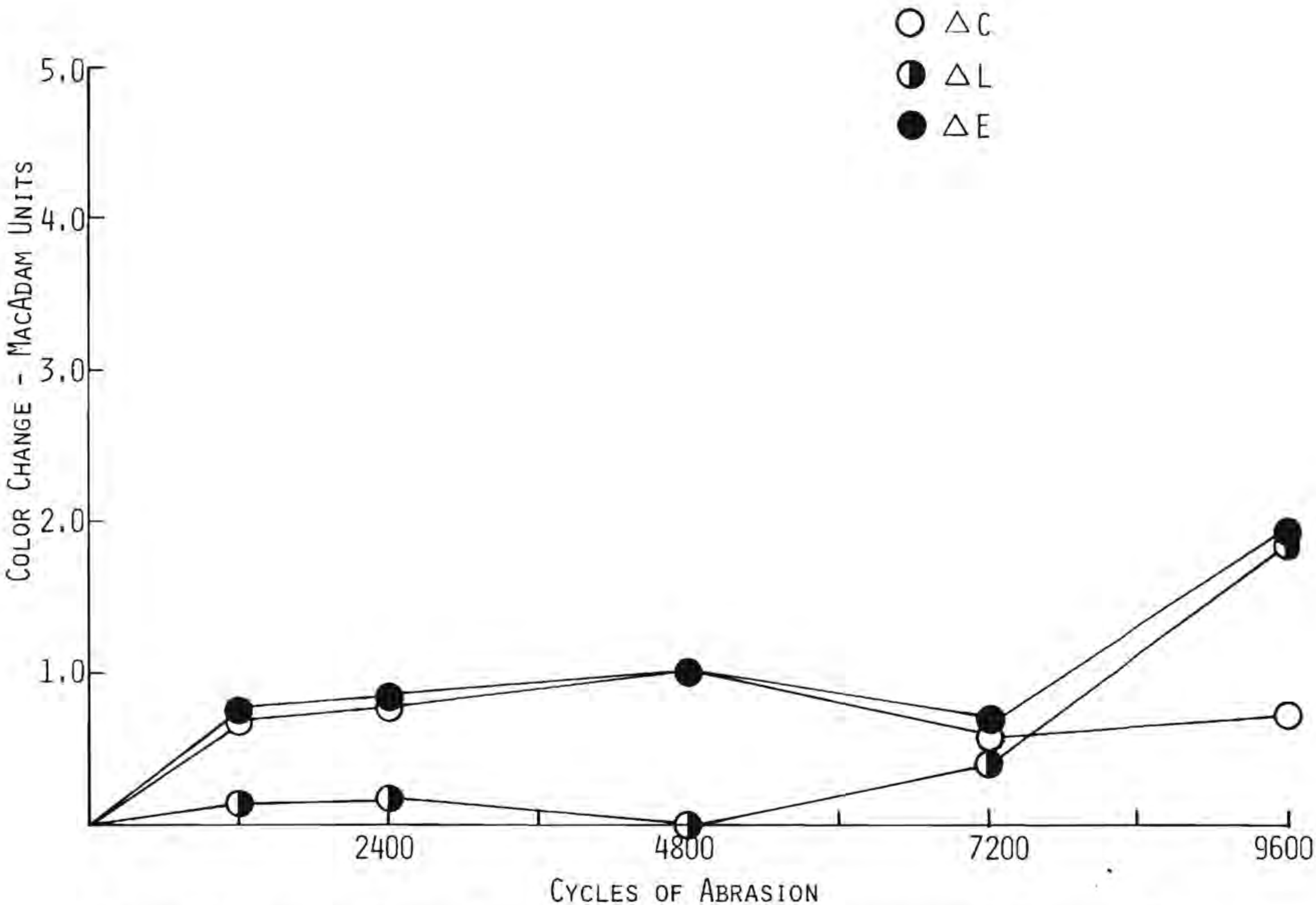

FIGURE 21. COLOR CHANGE DUE TO FLAT ABRASION - EXPERIMENTAL FABRIC F-9
(AATCC-119-1970)

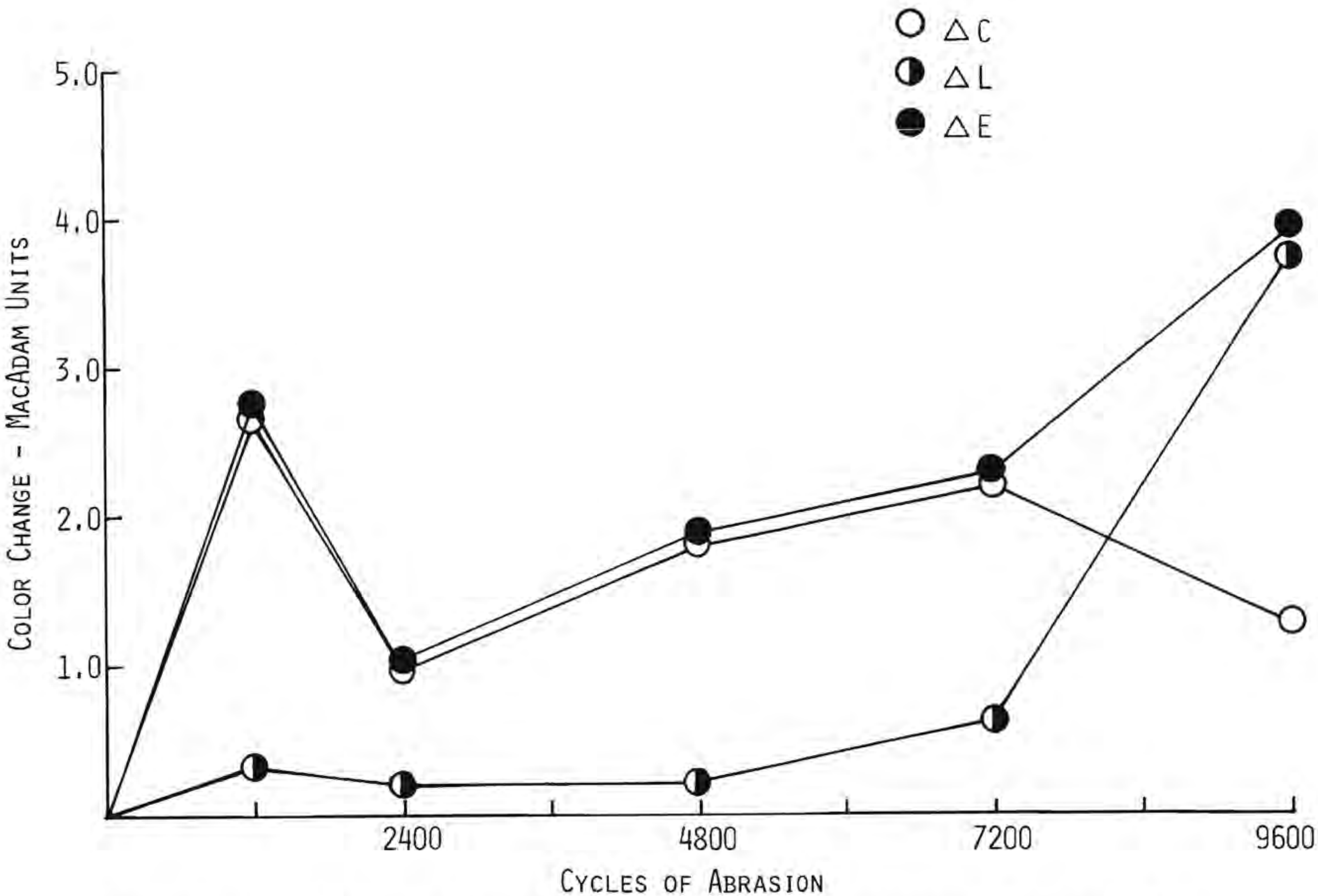

Figure 22. Color Change Due to Flat Abrasion - Experimental Fabric F-10
(AATCC-119-1970)

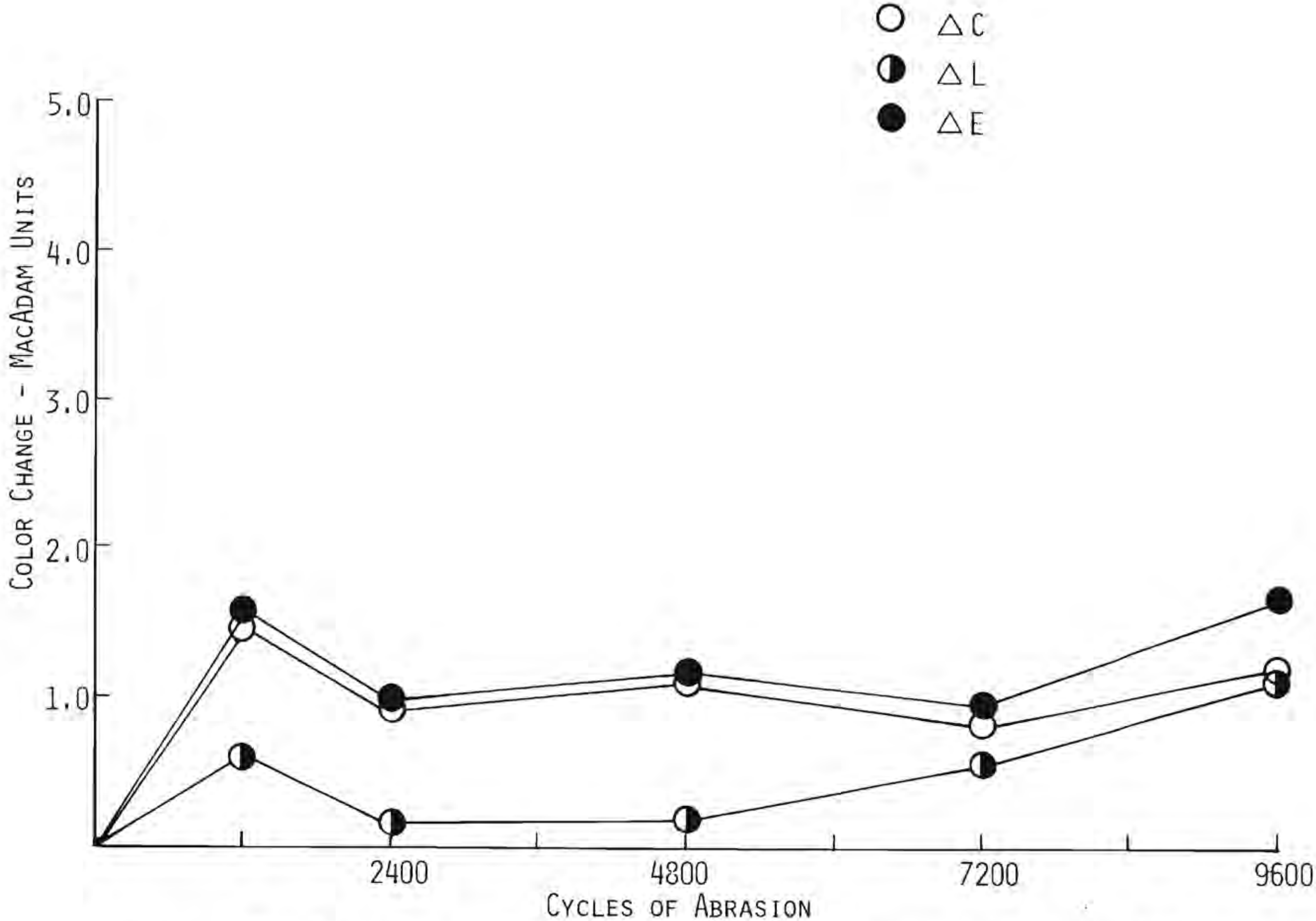

Figure 23. Color Change Due to Flat Abrasion - Experimental Fabric F-11
(AATCC-119-1970)

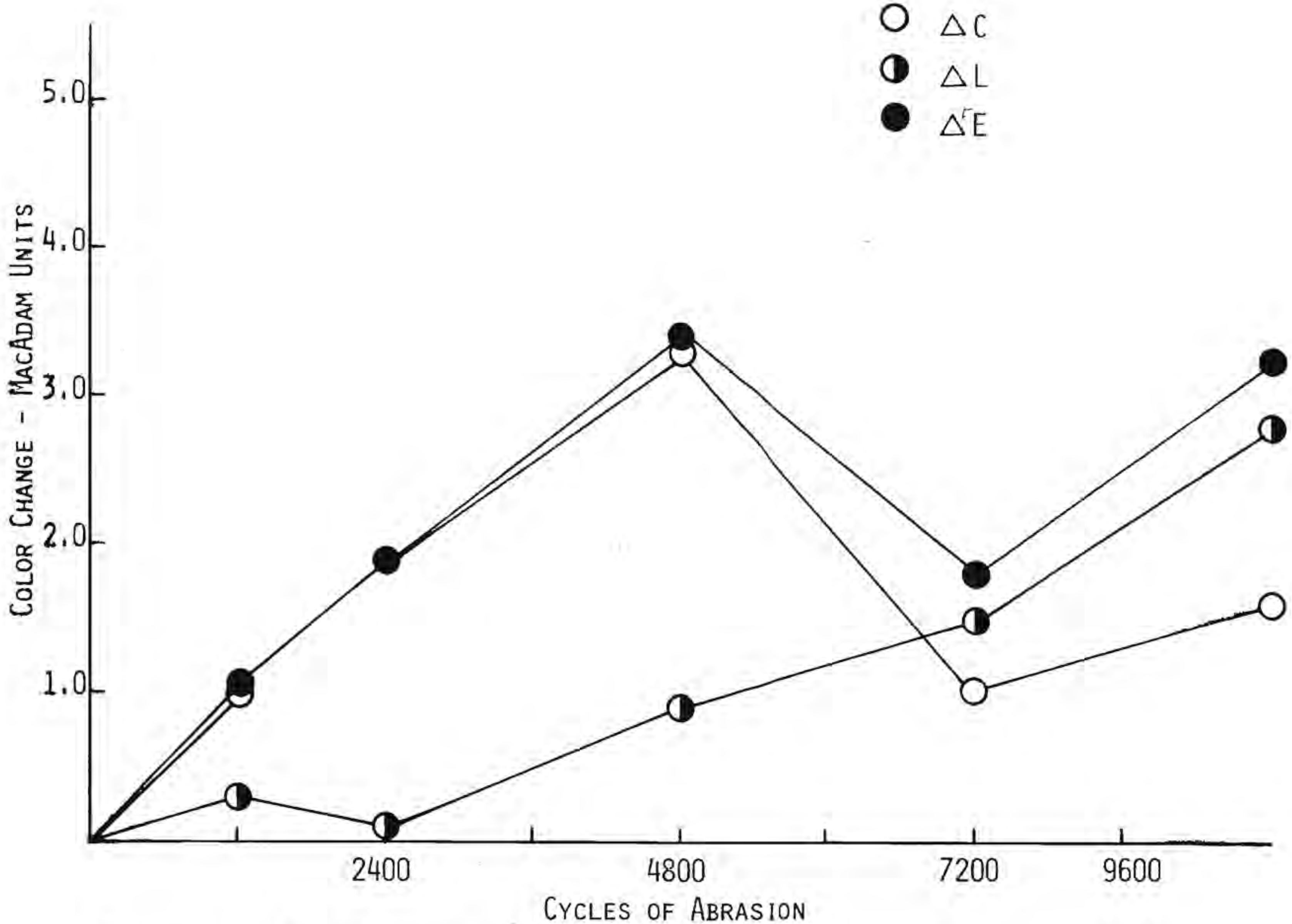

FIGURE 24. COLOR CHANGE DUE TO FLAT ABRASION - EXPERIMENTAL FABRIC F-12
(AATCC-119-1970)

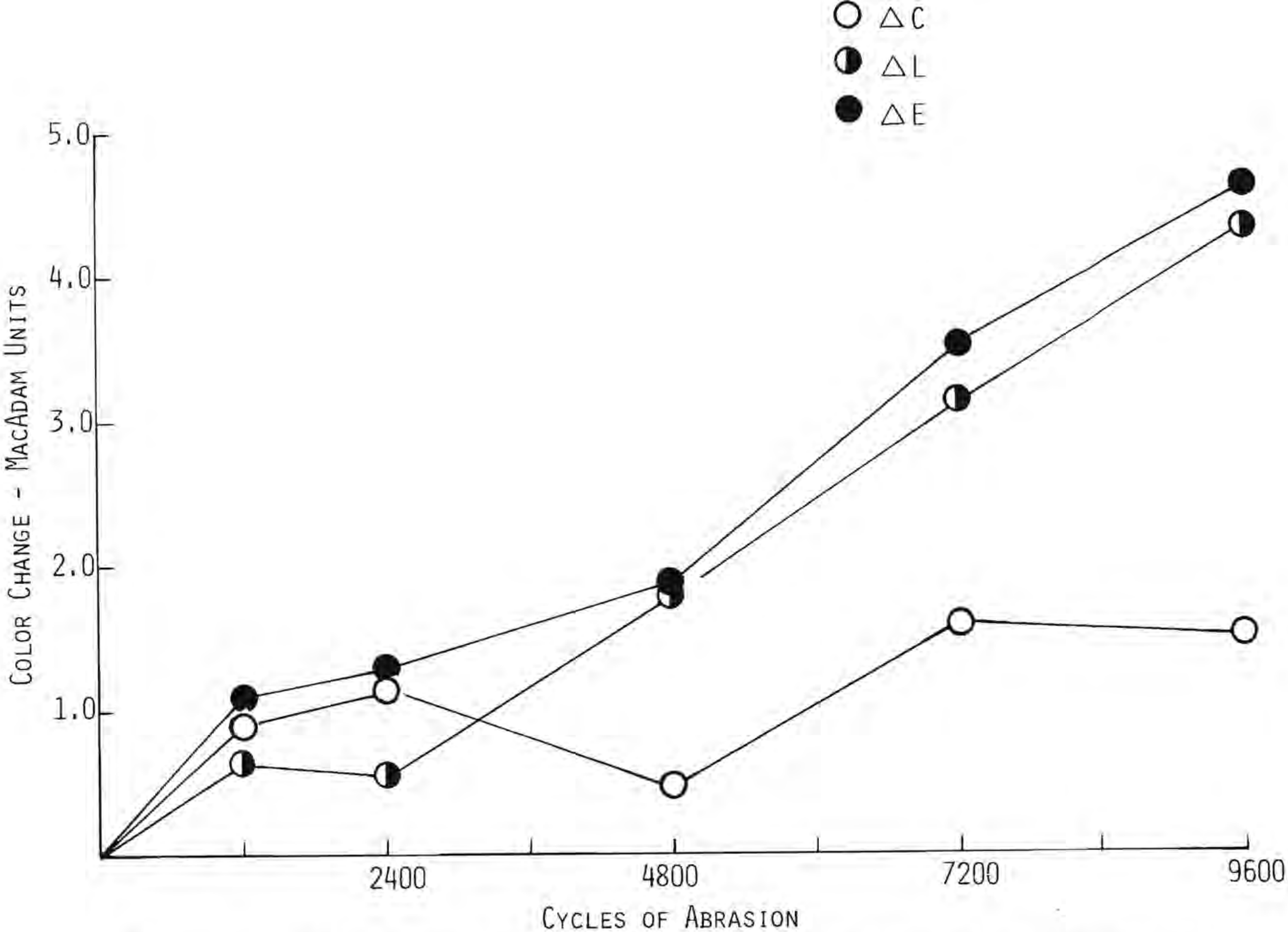

Figure 25. Color Change Due to Flat Abrasion - Air Force Blue 1549 Tropical Fabric - Standard No. 2 (9.0 oz. Type III, Class 1)

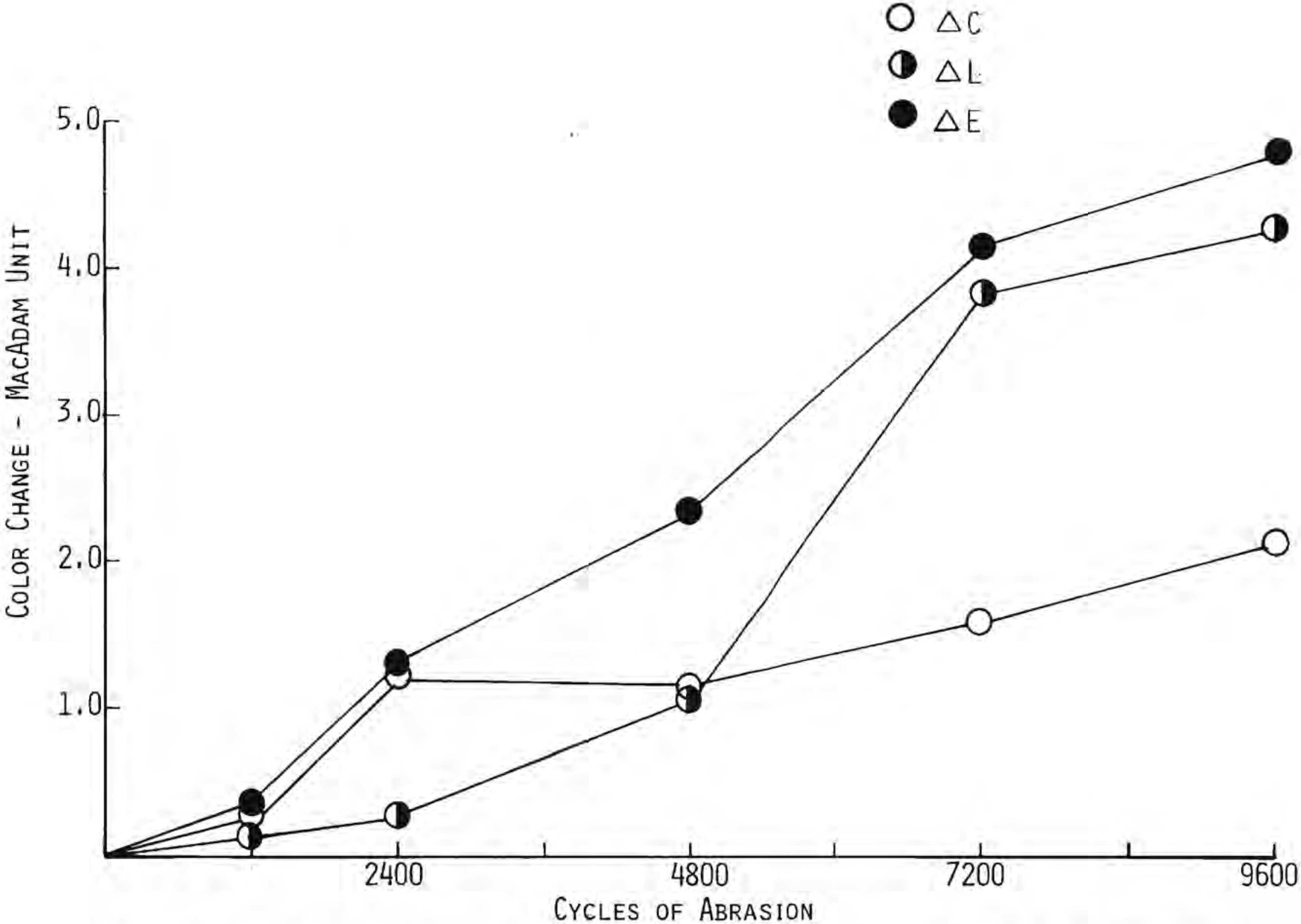

Figure 26. Color Change Due to Flat Abrasion - Air Force Blue 1549 Tropical Fabric - Standard No. 3 (10.0 oz. Type III, Class 3)

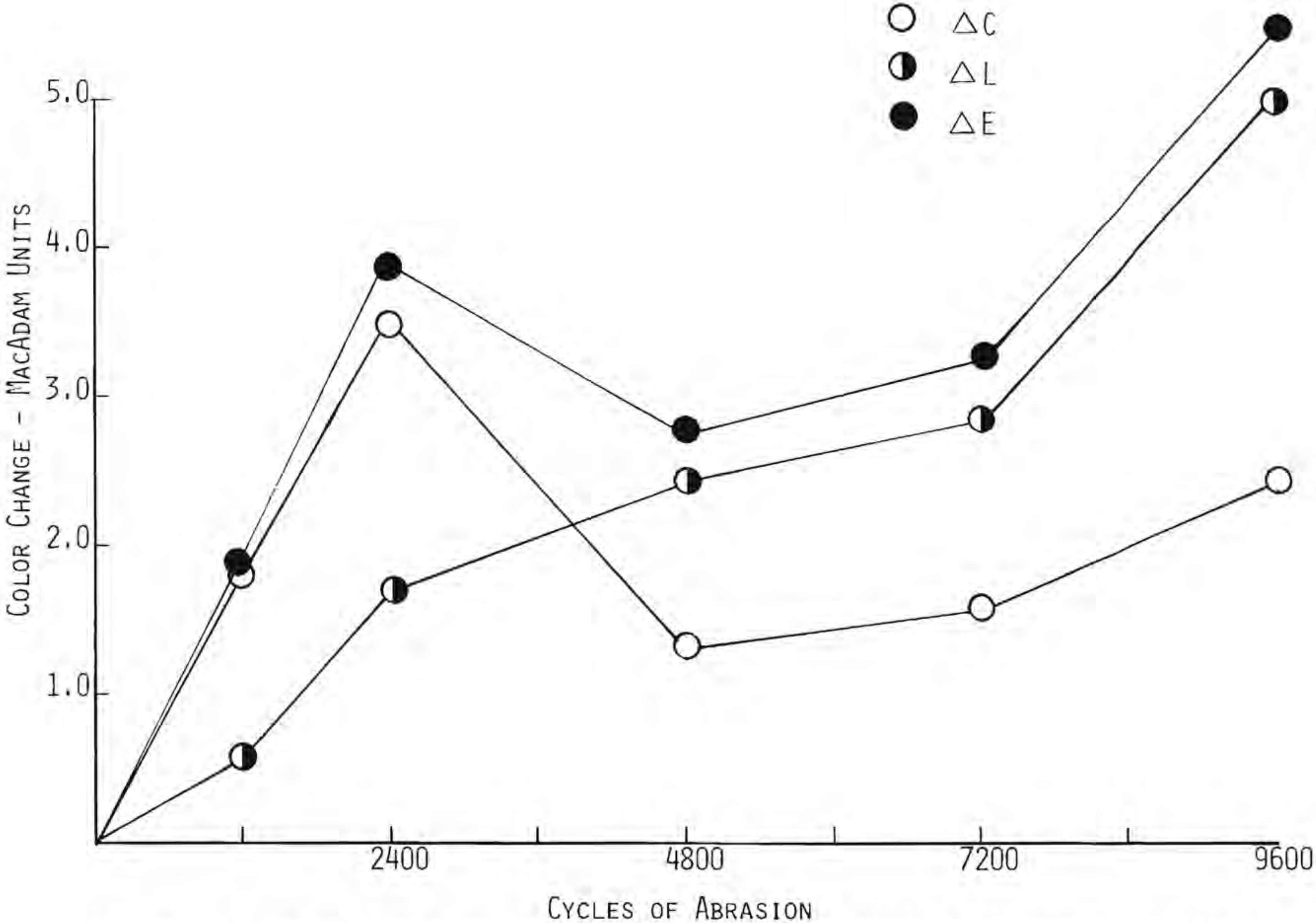

Figure 27. Color Change Due to Flat Abrasion - Air Force Blue 1549 Serge Fabric - (MIL-C-83048)

The color change on abrasion is greater for those fabrics which were carbonized than for those which were not carbonized. The variables of wool grade and yarn twist appear to be least important. The results of the statistical analysis are shown in Tables 36-38. and summarized in Table 39. It is seen that(1) Dacron 54 is preferred to Dacron 64 and Dacron 35, (2) the 60/40 (polyester/wool) blend is preferred, and (3) a yarn twist of 15 t.p.i is preferred to a yarn twist of 12 t.p.i.

m. Dry Cleaning

Six fabrics (F-4, F-6, F-9, F-10, F-11, F-12) were commercially dry cleaned using perchloroethylene and Stoddard solvent (10, 20, and 30 dry-cleanings). These fabrics were abraded to 4800 cycles; there was slightly more frosting of these fabrics than of ones not dry cleaned. The abrasion properties do not appear to be different for the two solvents used in dry cleaning.

n. Heat Set Treatment

Selected fabrics (F-6, F-9, F-10, F-11) were heat set to determine if their properties (drape, strength, bending length, wrinkle recovery) would be altered. There was a small reduction in breaking strength and no clear change in other properties as a result of heat setting; these results are shown in Table 40.

TABLE 36

FRACTIONAL FACTORIAL ANALYSIS OF VARIANCE FOR COLOR CHANGE (ΔE) DUE TO FLAT ABRASION

F Values Found ($V_1 = 1$, $V_2 = 36$)

1200 Cycles

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
2.19	9.10				.20
2.32		.81			.89
2.50			4.33		.23
2.79				.20	9.10
	8.67	.92			.24
	9.90		5.26		1.16
	9.10			.20	2.79
		.83	4.41		.17
		.83		.17	4.14
			4.14	.17	.83

2400 Cycles

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
3.96	.62				1.24
4.75		1.30			8.15
4.56			4.52		3.03
3.96				1.24	.62
	.59	1.04			2.53
	.13		4.64		8.02
	.62			1.24	3.96
		1.10	3.98		1.26
		1.10		1.26	3.98
			3.98	1.26	1.10

TABLE 36. Continued

4800 Cycles

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
1.08	16.87				5.27
.81		.30			7.02
.73			3.16		.03
1.08				5.27	16.87
	14.49	.34			.04
	21.51		5.98		12.02
	16.87			5.27	1.08
		.29	3.45		3.88
		.29		3.88	3.45
			3.45	3.88	.29

7200 Cycles

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
.23	13.91				.79
.18		.42			3.99
.20			7.81		.07
.23				.79	13.91
	13.75	.52			.08
	21.77		14.12		7.84
	13.91			.79	.23
		.47	8.00		.70
		.47		.70	8.00
			8.00	.70	.47

9600 Cycles

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
.12	1.71				10.37
.09		.00			.19
.14			15.57		4.65
.12				10.37	1.71
	1.45	.00			3.36
	1.87		14.56		.27
	1.71			10.37	.12
		.00	19.56		15.23
		.00		15.23	19.56
			19.56	15.23	.00

TABLE 37

FRACTIONAL FACTORIAL ANALYSIS OF VARIANCE FOR HUE CHANGE (ΔC) DUE TO FLAT ABRASION

F Values Found ($V_1 = 1$, $V_2 = 36$)

1200 Cycles

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
2.60	9.12				.28
2.16		.72			1.01
2.10			4.18		.19
2.60				.28	9.12
	8.68	.83			.15
	9.90		4.89		1.32
	9.12			.28	2.60
		.74	3.83		.24
		.74		.24	3.83
			3.83	.24	.74

2400 Cycles

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
4.54	.73				1.05
5.49		1.22			8.50
5.20			3.81		3.49
4.54				1.05	.72
	.69	.96			2.92
	.84		3.79		8.12
	.72			1.05	4.55
		.98	3.24		1.02
		.98		1.02	3.24
			3.24	1.02	.98

4800 Cycles

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
.79	.00				4.57
.73		1.06			.16
1.25			21.62		6.59
.79				4.57	.00
	.00	1.16			4.16
	.00		17.88		.22
	.00			4.57	.79
		1.90	22.38		7.49
		1.90		7.49	22.38
			22.38	7.49	1.90

TABLE 37. Continued

7200 Cycles

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
1.09	4.21				1.49
1.13		4.13			3.06
1.16			6.48		1.66
1.09				1.49	4.21
	4.59	4.35			1.71
	5.14		7.47		3.60
	4.21			1.49	1.09
		4.61	7.07		1.73
		4.61		1.73	7.07
			7.07	1.73	4.61

9600 Cycles

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
1.58	12.69				1.81
1.40		.95			7.89
1.23			3.38		.09
1.58				1.81	12.69
	11.96	1.01			.11
	17.44		5.95		12.21
	12.69			1.81	1.59
		.86	3.47		1.45
		.86		1.45	3.47
			3.47	1.45	.86

TABLE 38

FRACTIONAL FACTORIAL ANALYSIS OF VARIANCE FOR LIGHTNESS CHANGE (ΔL) DUE TO FLAT ABRASION

F Values Found ($v_1 = 1$, $v_2 = 36$)

1200 Cycles

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
14.84	1.33				10.79
11.57		.95			.57
15.53			.20		14.20
14.84				10.79	1.33
	1.02	.94			10.42
	1.79		.11		.44
	1.33			10.79	14.84
		.89	.13		1.63
		.87		7.65	.14
			.14	7.65	.87

2400 Cycles

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
19.42	.03				14.81
13.71		.17			.43
17.09			2.35		7.28
19.42				15.81	.03
	.02	.13			4.75
	.02		1.41		.33
	.03			15.81	19.42
		.16	1.83		10.83
		.16		10.83	1.83
			1.83	10.83	.16

TABLE 38. Continued

4800 Cycles

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
7.23	11.67				15.98
4.70		5.17			.23
5.02			.23		7.93
7.23				15.98	11.67
	10.54	7.18			10.33
	7.18		.20		.22
	11.67			15.98	7.23
		6.14	.25		12.34
		6.14		12.34	.24
			.23	12.34	6.14

7200 Cycles

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
21.42	24.24				.10
16.53		9.82			.74
17.60			3.31		5.08
21.42				.10	24.24
	22.36	11.74			5.33
	16.49		2.47		.65
	24.24			.10	21.42
		7.02	2.00		.06
		7.02		.06	2.00
			2.00	.06	7.02

9600 Cycles

Blend	Dacron	Wool	Carbonizing	Twist	Interaction
9.90	10.21				12.69
6.61		9.17			.17
6.35			1.48		.26
9.90				12.69	10.21
	6.88	3.20			.28
	6.62		1.49		.10
	10.21			12.69	9.90
		3.48	1.70		9.31
		3.48		9.31	1.70
			1.70	9.31	3.48

TABLE 39

SUMMARY OF FRACTIONAL FACTORIAL ANALYSES OF VARIANCE
FOR COLOR CHANGE DUE TO FLAT ABRASION

Level of Significance

	Variables					
Test	b	d	w	c	t	Comments on Levels of Significance**
Color Difference ΔE						
1200 Cycles		.99				1. Dacron 54 > Dacron 64
2400 Cycles	.95					1. 60/40 PET/Wool > 40/60 PET/Wool
4800 Cycles		.99				1. Dacron 54 > Dacron 64
7200 Cycles		.99		.95		1. Dacron 54 > Dacron 64 2. Not Carbonized > Carbonized
9600 Cycles				.99	.99	1. Not Carbonized > Carbonized 2. 15 tpi > 12 tpi
Hue Difference ΔE						
1200 Cycles		.99				1. Dacron 54 > Dacron 64
2400 Cycles	.95					1. 60/40 PET/Wool > 40/60 PET/Wool
4800 Cycles				.99	.95	1. Not Carbonized > Carbonized 2. 15 tpi > 12 tpi
7200 Cycles		.95	.95	.99		1. 60/40 PET/Wool > 40/60 PET/Wool 2. Wool 64-70s > Wool 64s 3. Not Carbonized > Carbonized
9600 Cycles		.99				1. Dacron 54 > Dacron 64

* b - Blend level
d - Type polyester
w - Grade of wool
c - carbonizing
t - yarn twist

**These comments relate to the variables studied. The symbol > signifies "preferred to", i.e., less objectionable color change due to flat abrasion.

TABLE 39. Continued

Test	b	d	w	c	t	Comments on Levels of Significance
Lightness Difference ΔL						
1200 Cycles	.99				.99	1. 60/40 PET/Wool > 40/60 PET/Wool 2. 15 tpi > 12 tpi
2400 Cycles	.99				.99	1. 60/40 PET/Wool > 40/60 PET/Wool 2. 15 tpi > 12 tpi
4800 Cycles	.95	.99	.95		.99	1. 60/40 PET/Wool > 40/60 PET/Wool 2. Dacron 54 > Dacron 64 3. Wool 64-70s > Wool 64s 4. 15 tpi > 12 tpi
7200 Cycles	.99	.99	.99			1. 60/40 PET/Wool > 40/60 PET/Wool 2. Dacron 54 > Dacron 64 3. Wool 64-70s > Wool 64s
9600 Cycles	.99	.99	.95		.95	1. 60/40 PET/Wool > 40/60 PET/Wool 2. Dacron 54 > Dacron 64 3. Wool 64-70s > Wool 64s 4. 15 tpi > 12 tpi

TABLE 40

FABRIC PROPERTIES AFTER HEAT SETTING

Breaking Strength (Ravel Strip) (lbs/in)

Fabric Designation	Before Heat Setting Warp	Before Heat Setting Filling	Heat Set 180°C Warp	Heat Set 180°C Filling	Heat Set 200°C Warp	Heat Set 200°C Filling
F-6	127	96	115	91	114	89
F-9	126	100	115	93	112	92
F-10	124	93	102	86	112	84
F-11	119	93	106	89	109	92

Bending Length (cm.)

Fabric Designation	Before Heat Setting Warp	Before Heat Setting Filling	Heat Set 180°C Warp	Heat Set 180°C Filling	Heat Set 200°C Warp	Heat Set 200°C Filling
F-6	2.2	2.0	2.0	1.9	2.1	1.9
F-9	2.1	2.1	2.1	2.1	2.1	2.1
F-10	2.3	1.9	2.0	1.9	2.0	1.9
F-11	2.3	2.1	2.2	2.1	2.1	2.1

Wrinkle Recovery (%)

Fabric Designation	Before Heat Setting Warp	Before Heat Setting Filling	Heat Set 180°C Warp	Heat Set 180°C Filling	Heat Set 200°C Warp	Heat Set 200°C Filling
F-6	86.5	85.1	86.1	83.3	86.7	85.0
F-9	87.8	83.7	92.2	84.9	87.2	87.1
F-10	91.8	85.5	92.2	87.3	86.3	87.8
F-11	86.7	84.6	89.3	87.5	90.2	80.4

Table 40. Continued

Drape

4 Inch. Pedestal

Fabric Designation	Before Heat Setting	Heat Set 180°C	Heat Set 200°C
F-6	0.45	0.37	0.47
F-9	0.43	0.45	0.45
F-10	0.40	0.41	0.49
F-11	0.42	0.42	0.43
	5 Inch. Pedestal		
F-6	0.46	0.49	0.58
F-9	0.54	0.59	0.48
F-10	0.42	0.50	0.52
F-11	0.50	0.45	0.54
	6 Inch. Pedestal		
F-6	0.48	0.60	0.63
F-9	0.71	0.75	0.69
F-10	0.65	0.60	0.65
F-11	0.59	0.66	0.71

o. Color Fastness

Color Fastness to wet dry cleaning

Color Fastness to crocking

Color Fastness to Light

Color Fastness to perspiration

All of the fabrics exhibited excellent dry-cleaning, crocking, and perspiration fastness. The light fastness ratings as shown in Table 41 were good but not as good as expected, probably due to the fact that the black-panel temperature in the Fade-Ometer was too high.

TABLE 41

COLOR FASTNESS TO LIGHT-GREY SCALE RATINGS

Fabric Designation	Exposure Time 10 Hr.	20 Hr.	40 Hr.	80 Hr.
F-1	5.0	5.0	4.0	3.0
F-2	5.0	4.5	4.0	3.0
F-3	5.0	4.5	3.5	2.5
F-4	5.0	5.0	4.5	3.5
F-5	5.0	4.5	3.5	2.5
F-6	5.0	5.0	4.5	4.0
F-7	5.0	4.5	4.0	3.0
F-8	5.0	4.5	4.0	3.0
F-9	5.0	4.5	3.5	3.0
F-10	5.0	5.0	4.5	4.0
F-11	5.0	5.0	4.5	4.0
F-12	5.0	5.0	4.5	4.0

E. Conclusions From Experimental Fabric Program

The experimental fabric program was designed to determine those factors in the composition, structure, and processing of wool/polyester uniform fabrics which contribute to their appearance and durability. Assessment of the relative importance of factors which affect fabric properties has been made by inspection of mean values for the fabric properties. In addition, the data was treated statistically as described above. The results of the statistical analyses of the fabric property data is in substantial agreement with the conclusions arrived at from an inspection of the mean values. The following conclusions can be drawn from this experimental fabric program:

1. The superiority in resistance to frosting of Dacron type 54 compared to both Dacron type 64 and Dacron type 35.

2. The small improvement in resistance to frosting obtained by using a 4.5 denier Dacron type 54 rather than a 3.0 denier Dacron type 54.

3. The small improvement in resistance to frosting by increasing the yarn twist in the singles and plied yarns from 12 t.p.i to 15 t.p.i., particularly for long times of abrasion.

4. The necessity for singeing to obtain good pilling resistance even with pilling-resistant fibers such as Dacron types 35 and 64.

5. The slightly better resistance to frosting afforded by a 60/40 polyester/wool blend fabric compared with 40/60 polyester/wool blend fabric.

6. In order to obtain a minimum color change on abrasion, the polyester component should be slightly darker in shade than the wool component.

7. The greater strength of Dacron type 54 compared with Dacron type 64 and Dacron type 35.

8. The grade of wool (64s versus 64-70s) has little effect on abrasion characteristics.

F. Critique of Experimental Fabric Program and Recommendations for Production Run Fabrics.

As a part of this program a Technical Conference was held at the Georgia Institute of Technology, 30 April, 1974 to provide a comprehensive discussion of the program to develop polyester/wool uniform fabrics with improved durability and appearance. A copy of the report of this conference is appended.

Based on the results of the work presented at the technical conference and its critique by experts in the manufacture and utilization of polyester/wool worsted fabrics, the following production-run fabrics were recommended:

Item No.	Polyester/Wool	Type Polyester	Type Wool	Remarks (56" width)
1.	55/45	Dacron 54 (4.5 dpf)	64s	9 oz. tropical (Type III, Class 1)
2.	55/45	Dacron 54 (3.0 dpf)	64s	9 oz. tropical (Type III, Class 1)
3.	55/45	Dacron 64 (3.0 dpf)	64s	9 oz. tropical (Type III, Class 1)
4.	55/45	Dacron 54 (4.5 dpf)	64s	10 oz. tropical (Type III, Class 3)
5.	55/45	Dacron 54 (3.0 dpf)	64s	10 oz. tropical (Type III, Class 3)
6.	55/45	Dacron 64 (3.0 dpf)	64s	10 oz. tropical (Type III, Class 3)

The first three fabrics, items 1, 2, and 3 were recommended to demonstrate the superiority of Dacron type 54 to Dacron type 64 and the improvement which is gained in replacing a 3.0 denier polyester fiber with a 4.5 denier fiber.

The last three fabrics, items, 4, 5, and 6 are duplicates of items 1, 2, and 3 except for difference in yarn count and ends and pick counts required to meet the specifications of the 10 oz. tropical fabric (Type III, Class 3). These three fabrics were included because of statements made by the representatives of the Clothing Branch, Aeronautical Systems Division, with respect to the contemplated replacement of the 9 oz. tropical fabric by the 10 oz tropical fabric.

SECTION V

PREPARATION AND EVALUATION OF PRODUCTION - RUN FABRICS

A. Description of Fabrics

The final phase of this contract consisted of the preparation of five hundred yard lots of polyester/wool fabrics to use in a three (3) year service test program to be conducted by the Clothing Branch, Aeronautical Systems Division. The description of the fabrics recommended to the Air Force Materials Laboratory technical monitor through the Procuring Contracting Officer is shown below in Table 42.

TABLE 42

DESCRIPTION OF RECOMMENDED PRODUCTION-RUN FABRICS

Fabric No.	Composition Polyester/Wool	Type Polyester	Type Wool (Grade)	Type Fabric*
1	57.5/42.5	Dacron 54 (4.5 dpf)	64s	9.0 oz. tropical (Type III, Class 1)
2	57.5/42.5	Dacron 54 (3.0 dpf)	64s	9.0 oz. tropical (Type III, Class 1)
3	57.5/42.5	Dacron 64 (3.0 dpf)	64s	9.0 oz. tropical (Type III, Class 1)
4	57.5/42.5	Dacron 54 (4.5 dpf)	64s	10.0 oz. tropical (Type III, Class 3)
5	57.5/42.5	Dacron 54 (3.0 dpf)	64s	10.0 oz. tropical (Type III, Class 3)
6	57.5/42.5	Dacron 64 (3.0 dpf)	64s	10.0 oz. tropical (Type III, Class 3)

*As defined in MIL-C-21115G (23 October 1970)

The first three fabrics were recommended to demonstrate the superiority in abrasion properties of Dacron type 54 compared with Dacron type 64 and the improvement which is gained by replacing a 3.0 denier polyester fiber with a 4.5 denier polyester fiber. The last three fabrics are duplicates of the first three fabrics except for the differences in yarn count and end and pick counts required to meet the specifications of the ten (10) oz. tropical fabric (Type III, Class 3)

It was recommended that all six fabrics have the same yarn and fabric construction as specified in MIL-C-21115G. It was further recommended that the yarn twist in both singles and ply yarns be 15 t.p.i. as contrasted with a twist level of 11 t.p.i. as found in the Air Force tropical standard fabric. It should be noted that the yarn twist is not specified in MIL-C-21115G. The preparation of these fabrics was subsequently approved by the Air Force Materials Laboratory technical monitor.

B. Production of Fabrics

The suppliers of materials and services in the preparation of the six (6) production-run fabrics were as follows:

Polyester tops and wool top

Burlington Industries Incorporated
Wellman, Incorporated

Dyeing and Blending of Dyed Tops

Florence Dye Works

Spinning of Yarns from dyed and blended tops

Westbrook Spinning Company

Weaving and Finishing of Fabrics

Methuen International Mills

The processing procedures used in the preparation of these fabrics were essentially the same as those used in the preparation of the experimental fabrics (see Figure 12). The polyester tops were prepared from polyester tow with the use of the Pacific Converter (3.5 in straight cut). The dyeing procedures differed from those used previously with respect to the dyeing formulations as shown below:

Dyeing of wool component:

3.0% M tin FF (o.w.f.)
1.0% Avalon IS (o.w.f.)
5.0% Ammonium Sulfate
0.86% Levelan Navy Blue IRL (o.w.f.)
0.53% Levenol Brilliant Blue FFG (o.w.f.)
0.036% Isolan Orange R (o.w.f.)
0.048% Isolan Yellow N.W.

The dyeing was carried out at the boil for 1.5 hours followed by the addition of 2.0% acetic acid (56%) and the dyeing was continued at the boil for an additional 15 minutes.

Dyeing of Polyester Component

Dacron 54 (4.5 dpf)

2.00%	Lyogen P
2.00%	Lyogen DFT
9.00%	Dilatin TC
3.67%	Foron Blue ER
1.24%	Foron Brilliant Red E-2BL
0.62%	Foron Yellow E-RGFL

Reduction scour with

3% Virtex PS (Virtex PS (Virginia Chemicals)

Dacron 54 (3.0 dpf)

2.00%	Lyogen P
2.00%	Lyogen DFT
9.00%	Dilatin TC
3.31%	Foron Blue ER
1.37%	Foron Brilliant Red E-2BL
0.69%	Foron Yellow E-RGFL

Reduction scour with:

3% Virtex P.S. (Virginia Chemicals)

Dacron 64 (3.0 dpf)

2.00%	Lyogen P
2.00%	Lyogen DFT
9.00%	Dilatin TC
3.15%	Foron Blue ER
1.32%	Foron Brilliant Red E-2BL
0.55%	Foron Yellow E-RGFL

Reduction scour with:

3%	Virtex PS (Virginia Chemicals)

Note: All percentages are based on the weight of the fiber dyed.

Once the tops had been dyed, the processing procedures for converting them to blended top and the subsequent spinning of the blended top to yarn, 40 and 37.5 worsted counts for the 9.0 and 10.0 oz fabrics respectively, were the same as those used in making the experimental fabrics. The twist in the singles yarn was specified to be 15 t.p.i. The singles were then plied using a twist of 15 t.p.i. in the ply to provide a balanced yarn.

The weaving of the fabrics was carried out so that the resulting fabrics would have the same construction as specified in MIL-C-2115G for Type III, Class 1 and Type III, Class 3 tropical polyester/wool fabrics.

The finishing processes were as follows:

1. singeing
2. scouring, rinsing, extraction
3. drying
4. fulling
5. scouring, rinsing, extraction
6. drying
7. shearing
8. decating
9. pressing

The finished fabrics were identified as follows:

Fabric 118-1	9.0 oz.(40s/2) 57.5/42.5 Dacron type 54, 4.5 dpf/Wool 64s
Fabric 118-2	10.0 oz.(37s/2) 57.5/42.5 Dacron type 54, 4.5 dpf/Wool 64s
Fabric 119-3	9.0 oz.(40s/2) 57.5/42.5 Dacron type 54, 3.0 dpf/Wool 64s
Fabric 119-4	10.0 oz.(37s/2) 57.5/42.5 Dacron type 54, 3.0 dpf/Wool 64s
Fabric 120-5	9.0 oz.(40s/2) 57.5/42.5 Dacron type 64, 3.0 dpf/Wool 64s
Fabric 120-6	10.0 oz.(37s/2) 57.5/42.5 Dacron type 64, 3.0 dpf/Wool 64s

Pin tickets were placed on the face of each piece and indelible markings on the back of each piece. Five (5) yards of each fabric were shipped to the Georgia Institute of Technology for evaluation. The remaining fabrics were shipped to the Air Force Materials Laboratory.

Fabric 118-1	6 pieces	487.5 yds.
Fabric 118-2	6 pieces	457.2 yds.
Fabric 119-3	6 pieces	535.6 yds.
Fabric 119-4	6 pieces	476.0 yds.
Fabric 120-5	6 pieces	529.1 yds.
Fabric 120-6	6 pieces	466.6 yds.

C. Evaluation of Production-Run Fabrics

The test methods used in the evaluation of the production-run fabrics are the same as those used in the evaluation of the experimental fabrics (see Table 6).

1. Fiber content

The target composition of the production-run fabrics was 57.5 per cent polyester and 42.5 per cent wool, with the polyester content being not less than 55 per cent and not more than 60 per cent. The results of the analyses of the fabrics are shown in Table 43 below:

TABLE 43

FIBER CONTENT OF FABRICS

Fabric	Polyester* (%)	Wool* (%)
118-1	57.3	42.7
118-2	59.6	40.4
119-3	57.1	42.9
119-4	57.2	42.8
120-5	56.5	43.5
120-6	56.3	43.7

* Conditioned Basis, 70°F, 65% R.H.

2. Yarn Counts

The yarn counts were specified as 40s/2 and 37s/2 worsted count for the 9.0 and 10.0 oz. fabrics respectively corresponding to equivalent singles counts of 20.0 and 18.5. Analyses of the yarns used in making the fabrics are shown in Table 44 below:

TABLE 44

YARN COUNT

Fabric No.	Yarn Count (Equivalent Singles Worsted Count)
118-1	19.8
118-2	18.3
119-3	20.4
119-4	18.6
120-5	19.9
121-6	18.3

3. Fabric Construction

The analyses of the end and pick counts as well as the target values as specified in MIL-C-2115G for Type III, Class 1 and Type III, Class 3 fabrics are shown in Table 45:

TABLE 45

FABRIC CONSTRUCTION OF PRODUCTION-RUN FABRICS

Fabric No.	Target* Warp	Target* Filling	Found Warp	Found Filling
118-1	54	42	55	46
118-2	50	44	51	46
119-3	54	42	55	44
119-4	50	44	52	45
120-5	54	42	57	44
120-6	50	44	51	46

*MIL-C-21115G

4. Yarn Twist

The yarn twist specified for the production-run fabrics was 15 t.p.i. in both the singles and ply yarns. The results obtained are shown in Table 46.

TABLE 46

YARN TWIST IN PRODUCTION-RUN FABRICS

Fabric No.	Yarn Twist (t.p.i.) Singles	Yarn Twist (t.p.i.) Ply
118-1	14.9	18.9
118-2	13.7	16.4
119-3	15.5	16.3
119-4	16.5	16.8
120-5	16.4	16.8
120-6	15.3	16.9

5. Weight and Thickness of Production-Run Fabrics

The fabric weights (oz/yd^2) and fabric thickness (in) for the production-run fabrics are shown in Table 47. It should be noted that all fabrics have lower weights than anticipated from previous experience in the production of the experimental fabrics. The yarn counts and end and pick counts predict the correct fabric weights for Type III, Class 1 and Type III, Class 3 fabrics. The fabrics made to be Type III, Class 1 (9.0 oz) are within the specifications set forth in MIL-C-21115G with respect to fabric weight; however, the fabrics made to conform to Type III, Class 3 (10.0 oz) are lighter than the specification for this fabric. Samples from two rolls of each fabric were tested and found to give the same results. There is no adequate explanation for the low weights of these fabrics.

TABLE 47

FABRIC WEIGHT AND THICKNESS
OF PRODUCTION-RUN FABRICS

Fabric No.	Fabric Weight oz/yd^2	Fabric Weight oz/yd*	Fabric Thickness (in.)
118-1	5.5	8.5	0.015
118-2	5.9	9.2	0.016
119-3	5.5	8.5	0.015
119-4	5.9	9.2	0.015
120-5	5.5	8.5	0.016
120-6	5.7	9.0	0.017

*56 inch width basis

6. Bending Length, Wrinkle Recovery, and Drape of Production-Run Fabrics

The values for the bending length, wrinkle recovery, and drape of the production-run fabrics are shown in Table 48.

TABLE 48

BENDING LENGTHS, WRINKLE RECOVERY, AND DRAPE
OF PRODUCTION-RUN FABRICS

Fabric No.	Bending Length (cm)		Wrinkle Recovery %		Drape		
	Warp	Filling	Warp	Filling	6"	5"	4"
118-1	2.2	2.1	96	91	0.73	0.64	0.50
118-2	2.3	2.2	94	92	0.85	0.60	0.48
119-3	2.2	2.1	95	89	0.64	0.57	0.42
119-4	2.2	2.0	95	92	0.73	0.54	0.35
120-5	2.2	2.0	94	92	0.66	0.57	0.40
120-6	2.2	2.0	93	91	0.70	0.52	0.37

*Diameter of discs used in making drape measurements.

7. Moisture Regain of Production-Run Fabrics.

The moisture regains of the production run fabrics conditioned at 70°F, 65 per cent relative humidity are shown in Table 49.

TABLE 49

MOISTURE REGAIN OF PRODUCTION-RUN FABRICS

Fabric No.	Moisture Content* (%)
118-1	4.7
118-2	3.8
119-3	4.2
119-4	3.9
120-5	4.3
120-6	4.2

*Fabrics conditioned at 70°F, 65 per cent relative humidity.

8. Air Permeability of Production-Run Fabrics

The air permeabilities of the production run fabrics are shown in Table 50. There appears to be no significant differences between the fabrics.

TABLE 50

AIR PERMEABILITY OF PRODUCTION-RUN FABRICS

Fabric No.	Air Permeability $ft.^3/min/ft^2$
118-1	100
118-2	97
119-3	96
119-4	91
120-5	86
120-6	79

9. Breaking Strength of Production Run Fabrics

The breaking strengths of the production run fabrics were determined by two methods, namely, a grab test and the ravel strip test. The results of these tests are shown in Table 51.

TABLE 51

BREAKING STRENGTH OF PRODUCTION-RUN FABRICS

	Grab Test		Ravel Strip Test	
Fabric No.	Warp (lb)	Filling (lb)	Warp (lb/in)	Filling (lb/in)
118-1	190	159	123	101
118-2	188	175	132	107
119-3	180	159	135	100
119-4	194	177	133	111
120-5	113	110	94	73
120-6	121	111	96	70

The superiority of Dacron type 54 to Dacron type 64 as far as strength is concerned is clearly demonstrated.

10. Impeller Tumble Test - Pilling

The production run fabrics were subjected to the Impeller Tumble Test for pilling resistance. All of the fabrics were rated "5" after being tumbled for 30 min. and 60 min. i.e., no pilling.

11. Abrasion Resistance of Production Run Fabrics

The production fabric were first subjected to flex abrasion using the Stoll instrument. The results obtained as shown in Table 52 clearly demonstrate the superiority of Dacron type 54 to Dacron type 64. A surprising result was that the fabrics containing 3.0 dpf Dacron type 54 were slightly better than those containing 4.5 dpf Dacron type 54.

TABLE 52

FLEX ABRASION OF PRODUCTION RUN FABRICS

Fabric No.	Cycles to Break Warp	Cycles to Break Filling
118-1	1240	7000
118-2	1080	800
119-3	2760	1670
119-4	2260	1640
120-5	387	190
120-6	316	200

The fabrics were then subjected to flat abrasion (wire screen method) in order to assess the frosting behavior of the fabrics. They were abraded for 2400, 4800, 7200, and 9600 cycles of abrasion after which the degree of color change was determined visually by reference to the AATCC Geometric Grey Scale for color change and instrumentally from spectrophotometric color measurements.

The results obtained visually are shown in Table 53.

TABLE 53

COLOR CHANGE OF PRODUCTION-RUN FABRICS
DUE TO FLAT ABRASION

Fabric No.	Grey Scale Rating, Cycles of Abrasion: 2400	4800	7200	9600
118-1	4 - 5	3 - 4	4	3 - 4
118-2	5	4	4	3 - 4
119-3	5	4 - 5	4	4
119-4	4 - 5	4	3 - 4	3
120-5	4 - 5	4	3	3
120-6	4 - 5	3 - 4	3 - 4	2 - 3
Air Force Std. No. 2	4 - 5	3 - 4	3 -	3

It is concluded from these data that the fabrics containing Dacron 54 (both 3.0 and 4.5 dpf) show less color change (frosting) than fabrics containing Dacron 64 (fabrics 120-5 and 120-6), particularly at 9600 cycles of abrasion. This is not apparent for 2400 cycles of abrasion. At intermediate severity of abrasion, 4800 and 7200 cycles, there appears to be some preference for Dacron 54. The small improvement in abrasion behavior in the experimental fabric program for 4.5 denier Dacron 54 compared with 3.0 denier Dacron 54 is not apparent in these data.

The color changes due to abrasion as measured spectrophotometrically are shown in Table 54.

TABLE 54

COLOR CHANGE OF PRODUCTION-RUN FABRICS
DUE TO FLAT ABRASION

Fabric No.	Cycles of Abrasion	ΔE*	ΔC*	ΔL*	C-RG	C-YB
118-1	2400	3.23	3.23	.13	-.07	-.11
	4800	1.79	1.04	1.46	-.02	-.02
	7200	1.07	.62	.87	-.01	-.05
	9600	1.61	1.06	1.21	-.02	-.09
118-2	2400	2.17	2.17	.07	-.04	-.14
	4800	2.04	.62	1.94	-.01	-.05
	7200	3.31	1.03	3.15	-.02	-.01
	9600	2.04	.74	1.90	-.01	-.06
119-3	2400	2.61	2.49	-.79	-.05	-.15
	4800	2.68	2.65	.43	-.05	-.15
	7200	2.65	2.38	1.16	-.05	-.14
	9600	1.95	1.64	1.05	-.03	-.14
119-4	2400	1.46	1.45	.22	-.02	-.13
	4800	1.94	1.44	1.30	-.03	-.10
	7200	3.39	2.99	1.59	-.06	-.08
	9600	2.91	.70	2.83	-.01	-.04
120-5	2400	1.00	.99	.14	-.01	-.10
	4800	1.90	1.40	1.34	-.03	-.08
	7200	4.11	2.39	3.34	-.05	-.01
	9600	2.99	1.73	2.44	-.04	-.05
120-6	2400	1.73	1.68	.41	-.03	-.14
	4800	2.69	1.04	2.48	-.04	-.07
	7200	2.46	.73	2.35	-.01	-.08
	9600	4.48	1.71	4.14	-.04	-.02

* MacAdam Units of Color difference between the unabraded and abraded samples

The only conclusion that can be clearly drawn for the spectrophotometric data is that fabrics containing Dacron 54 (fabrics 118-1, 118-2, 119-3, and 119-4) show less frosting than those fabrics containing Dacron 64 (fabrics 120-5 and 120-6). The 9.0 oz. fabric containing Dacron 54, 3.0 dpf (fabric 119-3) appears to show less frosting than other fabrics containing Dacron 54. This finding was not in agreement with results obtained on the experimental fabrics.

11. Shrinkage of Production Run Fabrics

The allowed shrinkage according to MIL-C-21115G is a maximum of 2.5 and 2.0 per cent in the warp and filling directions respectively. All of the production run fabrics meet these specifications as shown in Table 55.

TABLE 55

SHRINKAGE OF PRODUCTION-RUN FABRICS

Fabric No.	Shrinkage (%) Warp	Filling
118-1	1.7	0.8
118-2	1.1	0.6
119-3	2.3	1.1
119-4	2.0	0.9
120-5	2.3	0.6
120-6	2.0	1.7

12. Colorfastness of Production-Run Fabrics

Colorfastness tests included fastness to dry cleaning, to crocking, to perspiration, and to light (xenon). With respect to dry cleaning, crocking, and perspiration, all of the fabrics were rated excellent, i.e., no change in dry cleaning, no transfer of color in crocking, and no shade change or transfer of color with respect to perspiration. The grey scale ratings for light fastness were 4-5 at 40 hours exposure and either 4 or 4-5 after 80 hours exposure. It was concluded that all of the fabrics meet the military standard for light fastness. The light fastness data are shown in Table 56.

TABLE 56

LIGHT FASTNESS OF PRODUCTION-RUN FABRICS

	Color Change (Grey Scale Rating)			
Fabric No.	10 hrs.	20 hrs.	40 hrs.	80 hrs.
118-1	5	5	4-5	4-5
118-2	5	5	4-5	4-5
119-3	5	5	4-5	4
119-4	5	5	4-5	4-5
120-5	5	5	4-5	4-5
120-6	5	5	4-5	4

SECTION VI

CONCLUSIONS

The objective of this work was exploratory research, development, and evaluation of polyester/wool Air Force Blue 1549 uniform fabrics having improved drape, handle, fabricability, wear, and resistance to "frosting" over current Air Force fabrics. The project was carried out in three phases, namely,

1. Determination of the cause of "frosting" of polyester/wool fabric and an assessment of those factors in the composition, construction, and processing of polyester/wool uniform fabrics which contribute to their abrasion behavior.

2. Design, fabrication, and evaluation of experimental fabrics to serve as a basis for the production of fabrics having improved abrasion properties.

3. Production and evaluation of six specification fabrics having improved properties required for the fabrication of uniforms which will undergo a three (3) year service test to be conducted by the Clothing Branch, Aeronautical Systems Division.

From a detailed examination of a worn Air Force uniform and the abrasion characteristics of a standard Air Force tropical fabric (Type III, Class 1), it was concluded that the wool component of the fabric is worn away preferentially and the frosted appearance of both the worn uniform and the abraded standard fabric is due primarily to the polyester component, its fibrillation resulting in an increase in light scattering and thus an increase in the luminosity of the fabric. Therefore, in the examination of those factors in the composition, construction, and processing of uniform fabrics, the focus was primarily on the polyester component of the blend. Exploratory work in the program led to the conclusion that there are many factors which must be considered in the development of a more durable uniform fabric and the task of evaluating each of the factors would be formidable. Therefore, those factors considered to be most important in abrasion were chosen for further study. These include

1) type of polyester fiber
2) denier of polyester fiber
3) grade of wool
4) fabric carbonizing
5) relative amounts of wool and polyester fiber in fabric
6) yarn twist
7) fabric singeing

A statistically designed experiment including these factors was carried out. A complete evaluation of the properties of the experimental fabrics led to the following conclusions:

1) The type of polyester used in the uniform fabrics has a pronounced effect on their abrasion (frosting) properties, e.g., Dacron type 54 is superior to both Dacron type 64 and Dacron type 35.

2) There is a small improvement in resistance to frosting obtained by using a 4.5 denier polyester fiber rather than a 3.0 denier polyester fiber (Dacron type 54).

3) An increase in yarn twist from 12 t.p.i. to 15 t.p.i. results in a small improvement in resistance to frosting.

4) Singeing of uniform fabrics is required in order to obtain fabrics with good resistance to pilling.

5) A 60/40 polyester/wool fabric has slightly better resistance to frosting than a 40/60 polyester/wool fabric.

6) In order to obtain minimum color change on abrasion, the polyester component should be darker in shade than the wool component.

7) The strength of uniform fabrics is a function of the type polyester fiber used, e.g., fabrics containing Dacron type 54 are much stronger than fabrics containing Dacron type 64.

8) The grade of wool (64s versus 64s-70s) has little effect on abrasion characteristics.

Based on the results obtained in the experimental fabric program, six (6) specification fabrics (approximately 500 yards of each) were prepared to demonstrate the superiority in abrasion properties of Dacron type 54 compared with Dacron type 64 and the improvement which is gained by replacing a 3.0 denier polyester fiber with a 4.5 denier polyester fiber. These fabrics have been completely evaluated. It is concluded that fabrics containing Dacron 54 are indeed superior to fabrics containing Dacron 64; however, the improvement expected by using a 4.5 denier fiber was not found. These six (6) fabrics will be made into uniforms for a service test program to be conducted by the Clothing Branch, Aeronautical Systems Division. The results of this program may reveal performance characteristics not apparent from laboratory evaluation results.

SECTION VII

RECOMMENDATIONS

With respect to the durability and resistance to "frosting" of uniform fabrics, the major considerations in the composition and construction of the fabrics are the type polyester used, its size (diameter) relative to that of wool, and the amount of twist in the yarns. It is recommended that the choice of the type polyester be based on its resistance to abrasion. In this work, Dacron type 54 was found to be superior to the chemically modified Dacron type 64. It is also recommended that consideration be given to the use of a polyester fiber having a diamter approximating that of the wool with which it is blended to demonstrate the improvement in spinning performance and abrasion characteristics which would result. An increase in yarn twist over that found in the Air Force standard fabric (Type III, Class 1) has been shown to give some improvement in abrasion resistance.

With respect to processing conditions, the following recommendations are made:

1. The wool and polyester components should be dyed separately in top form.
2. Carbonizing of fabrics should be avoided if feasible.
3. Good singeing and shearing of fabrics is demanded for optimum resistance to pilling and frosting.

References

1. Technical Manual of the American Association of Textile Chemists and Colorists, Test Method 119-1970, p. 108, 1970

2. Omura, Yasuski, et al., "Pilling of Wool Fibers," Journal of the Textile Machinery Society of Japan, 17, 61 (1971)

3. Gobeil, N.B. and D'alessandro, P.L., "A Proposed Test Method to Evaluate Frosting Potential Caused by Abrasive Wear", American Dyestuff Reporter, 22, 992 (1965).

4. Colledge, R., "Polyester Blends : How They React to Flat Abrasion Modern Textile Magazine, 42, 23 (1966)

5. Colledge, R., "Use of Wearer Trials to Establish a Laboratory Test for Pilling," Canadian Textile Journal, 84, 41 (1967).

6. Nilson, I.U., et al., "Pilling of Wool/Terylene Blended Fibers," Textile Institute Journal, 48, T374 (1957)

7. Elder, H.M. and Ferguson, A.S., "The Abrasion Resistance of Some Woven Fabrics as Determined by the Accelerotor Abrasion Tester," Textile Research Journal, 60, 251 (1969).

8. Belleli, T., "The Pilling of Fabrics," Fibres, 237 (Aug., 1958).

9. Gentis, David, "The Mechanism of Pilling," Textile Research Journal, 29, 578 (1959)

10. Brand, R. H., and Bohmfolk, B.M., "A Mathematical Model of Pilling Mechanism", Textile Research Journal, 37, 467 (1967)

11. Fortier, Pierre, "The Cause and Control of Pilling in Textiles", Textile Forum, 30 (June, 1965)

12. Brickenden, E. K., "Pilling - Its Control and Laboratory Measurement Canadian Textile Journal, 75, 57 (1958).

13. Mims, N.M., "Pilling - Causes and Cures", Man-Made Textiles, 33, 46 (1957)

14. Patton, J.P., "Report of Subcommittee on Frosting - National Research Committee RA-29, American Dyestuff Reporter, 55, 638 (1966).

References continued

15. Patton, J.P., "Colorfastness to Abrasion", Textile Chemists and Colorists, 6, 40 (1974)

16. Farmer, L.B., Et Al., "A New Test Method for Pilling," Textile Chemists and Colorists, 4, 167 (1972)

17. Livesay, B.R., A fatigue apparatus modified for rapid measurement of abrasion behavior of single filaments (textile fibers). A description of apparatus is being prepared for publication. Georgia Institute of Technology.

18. "Two-Way Analysis of Variance with Replicates," Hewlett-Packard Calculator, Vol. 1, 11-17, 9100B, Stat-Pac VII-3.

19. Kaswell, E.R., "Textile Fibers, Yarns, and Fabrics," Reinhold Publishing Corporation, p. 435 (1953).

APPENDIX I

Report of Technical Conference

30 April, 1974

Polyester/Wool Uniform Fabrics with Improved Durability and Appearance

As a part of the work being done at the Georgia Institute of Technology under Contract No. F33615-72-C-1822, a technical conference was held April 30, 1974 to provide a comprehensive discussion of the program to develop polyester/wool uniform fabrics with improved durability and appearance. The conference was held at the School of Textile Engineering, Georgia Institute of Technology. Those attending including representatives of polyester fiber producer interests, wool interests, textile producer interests, and representatives of ASD/ENCU and Natick Laboratory who have considerable expertise in the fabrication and performance of military uniforms.

The conference consisted of a morning session for the presentation of the Georgia Tech program and an afternoon session devoted to a critique of the program and the recommended production run fabrics. Industry assessment of the adaptability of newly developed fabrics to current production methods was also sought, including all aspects of production from the choice of raw materials, yarn and fabric construction, dyeing and finishing processes, to uniform fabrication.

The morning presentation was well received and, almost without exception, the participants were complimentary of the work which had been done. The conclusions that were drawn from the work were:

1. the superiority in resistance to frosting of Dacron type 54 compared to both Dacron type 64 and Dacron type 35.
2. the small improvement in resistance to frosting obtained by using 4.5 denier Dacron type 54 rather than a 3.0 denier Dacron type 54.
3. the improvement in resistance to frosting by increasing the yarn twist in both the singles and plied yarns from 12 t.p.i. to 15 t.p.i.
4. the necessity for fabric singeing to obtain good pilling resistance even with pilling-resistant fibers such as Dacron types 64 and 35
5. the slightly better resistance to frosting afforded by a 60/40 polyester/wool blend fabric compared with a 40/60 polyester/wool blend fabric and
6. The superior processing characteristics of 4.5 denier Dacron 54 compared with 3.0 denier Dacron 54, particularly in dyeing, blending, and spinning.

These conclusions were consistent with the experience of the participants.

Dr. Andreen (duPont), was in agreement that the use of 4.5 denier Dacron type 54 was a good idea, but he pointed out that textile mills prefer to use, if possible, only one fiber type and denier which gives them flexibility in several yarns and fabrics rather than a variety of fiber types and deniers. He also pointed out that the small potential improvements in resistance to frosting afforded by the 4.5 denier fiber should be verified in wear tests.

Mr. Hildebrandt (Methuen) and Mr. Spencer (Westbrook Spinning) who have had considerable experience in processing polyester-wool blends, pointed out that the processability of the 4.5 denier polyester fiber with wool was superior to that of the 3.0 denier fiber. Mr. Guerin (Florence Dye Works) has stated, by letter, that in the top blending operation, the 4.5 denier fiber is superior to the 3.0 denier fiber. Mr. Reynolds (duPont) stated that his work has shown that this is true. He pointed out that, although the spin limits for the 4.5 denier fiber with 64s wool is about 45s worsted count yarn, there was no reason for any difficulty in making the 40's yarn required in the tropical 9.0 oz. fabric. Mr. Spencer claimed that he had successfully made yarn of excellent quality having a worsted count of 48 using 4.5 denier polyester fiber. It should be noted that this count lies outside the spin limits stated by Mr. Reynolds. It would appear that, from a technical standpoint, there are two factors to be considered in the selection of a 4.5 denier in place of a 3.0 denier fiber, namely,

1. processability of the two fibers and
2. the relative merits of the two fibers from the standpoint of their resistance to frosting as determined from extensive wear tests.

Mr. Campbell (Natick) pointed out that the shade difference between the polyester and wool components is an important factor in the color change on abrasion. His recommendation is that the polyester component should be about twenty per cent heavier in depth of shade than the wool component.

Mr. Reynolds was questioned privately concerning the importance of yarn twist on abrasion (frosting and pilling). He has concluded from his work that the optimum twist in both the singles and ply yarn for the tropical fabric is 13 to 14 t.p.i. We have found in our work that 15 t.p.i. was slightly better than 12 t.p.i.

The question was raised as to whether the experimental fabrics meet the government specifications on shrinkage. These specifications are 2.5

and 2.0 per cent in the warp and filling directions, respectively. At the time of the conference, these measurements had not been made. The tests have now been completed and all the fabrics fall well within the government specifications.

With respect to the finishing of the experimental fabrics, it was concluded from the description of the finishing processes used that the fabrics had been finished in a manner consistent with the finishing of all-wool worsted fabrics. The thermal treatments in finishing were not as severe as those used for fabrics which contain a substantial quantity of polyester fiber. There was no indication that such treatments are either desirable or necessary. However, for completeness in this program, selected fabrics will be thermoset to determine the effect of such treatments on fabric properties.

It was the concensus of those participants who voiced an opinion on the "hand" of the experimental fabrics that even though the fabrics made using 3.0 denier Dacron type 54 could be easily distinguished from the fabric made using 4.5 denier Dacron type 54, both fabrics had a "hand" superior to that of the tropical standards. Although we have subsequently made drape measurements on all of the experimental fabrics (FRL Method), it is difficult to assess the effect of variables in composition and construction on the drape coefficient due to the variations in fabric weight and the variations in the number of nodes exhibited by the hanging fabrics. In any case, all of the fabrics had lower values for their drape coefficients than that for the tropical standard.

E-20-653

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29 December 1975

Subject: Final Technical Letter Report

To: Charles A. Babendreier
Engineering Mechanics Section
National Science Foundation

1. Name of Institution: Georgia Institute of Technology
2. Name of Principal Investigator: Daniel W. Halpin
3. Grant No.: ENG74-13131 A01

   Formerly: GK-42994
4. Starting Date: 1 May 1974
5. Completion Date: 31 December 1975
6. Grant Title: A Computerized Construction Management Gaming Environment
7. Brief Description of Research and Results

The objective of this research has been to develop a computerized construction management gaming environment which can be used to confront the student with the realities of the construction situation.

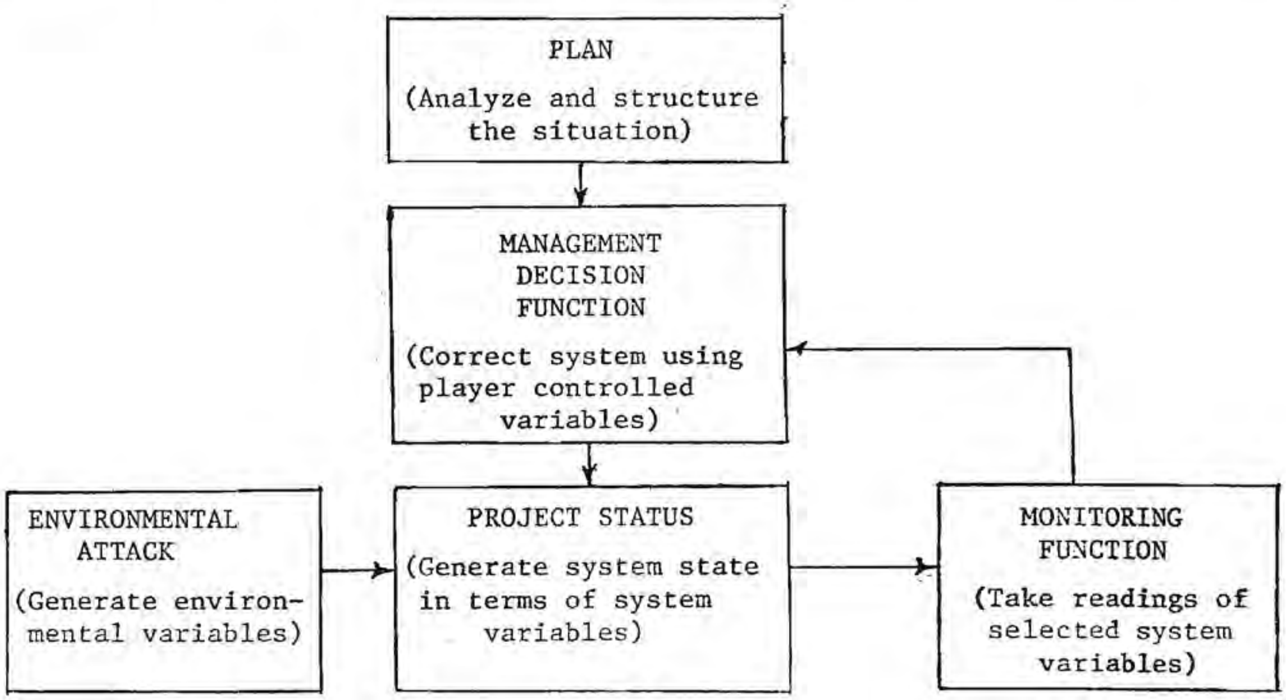
The purpose of the gaming environment is to provide the student with a multilevel adaptive learning experience. This is achieved by allowing the player to enter the construction environment at a very rudimentary level and work himself into the situation to an increasing degree of relevance (e.g., improved model to real-world mapping). Having mastered the linkages or relationships at this point of entry, he can progress up the ladder of management decision capitalizing on experience gained at one level to cope with the next. That is, he can carry his experience forward in much the same fashion it is presently acquired "on the job."

A prototype model focusing at the project and process levels of construction management has been developed. The project level game utilizes the network structure of the CONSTRUCTO game. (See Reference 1). For clarity of presentation, a description of the CONSTRUCTO game and its problem-oriented

(POL) input format is presented in the Final Report (Reference 3). The process level modeling is conducted within the context of the CYCLONE modeling format (See Reference 2). The CYCLONE*GAME sub-module is described in Chapters 4, 5 and Appendix B of the final report. Both the CONSTRUCTO and CYCLONE*GAME sub-components of the modeling environment can be played separately or in the COMPOSITE GAME format.

This environment is designed so that once the student becomes sufficiently familiar with the gaming environment, he can structure his own situations based on field observations of actual construction. In this way, the gaming environment provides the student with a laboratory experience within which he can develop his own experiment and decide upon appropriate actions. The necessity of structuring his own model focuses the player's attention on the nature of the situation and causes him to consider and try to better understand the problems he will be confronted with in the real world of construction.

The concept of the gaming environment is developed in terms of the components of the decision cycle shown below.



The Management Decision Cycle

Figure 1

At the outset of each gaming session, the player is requested to construct the framework or structure of the situation to be considered. That is, he is requested to provide a logical plan for the development of events across time. This plan is submitted to the computer in network format. The computer requests the plan information in terms of a network representation of the tasks and activities to occur across time. This input information initializes the game situation.

This initial plan submittal may represent the situation in two ways depending upon the level of play being defined:

1. For formulating project level situations the plan is submitted as a rigid logic network across a planning horizon defined by the player. In this mode, the plan provides structure for the game as time flow moves acyclically from the zero or start point to the end point of the project defined. The initially submitted network is stepped across in monthly time increments until the task or activities involved are all completed. This is the type of plan structure associated with the PERT and CPM concepts used in project planning and scheduling. This level of control is modeled in the context of the project oriented management game CONSTRUCTO and confronts the student with the problem of project management.

2. The second method of defining the game structure can be used alone or in conjunction with the project-spanning network. This method is also based on a network representation of the situation to be modeled. It, however, allows for cyclical flows and is well-adapted to modeling repetitive construction precesses. Such cyclic processes are very common to the construction field as well as many others.

The second stage of the management decision cycle has to do with the management or decision function itself. It is in this phase that the manager or the player, in our case, tries to exert his influence on the developing situation by use of the decision variables at his disposal. This set of variables must be defined during each game. These are the decision or controlled variables. As the modifier "controlled" implies, these are the variables over which the decision maker or the player has control and in terms of which he makes his decisions. The decision options available to the player vary depending upon the level in the gaming hierarchy which is being simulated.

The next aspect of the decision cycle is the development of the environment which is a set of uncontrolled variables which the gaming package provides. Two performance modifying factors are involved in defining the gaming environment:

1. Standard environmental attacks or backgrounds provided in the gaming package which can be called from a file library. These are developed in the form of "templates" as discussed in It is possible to define various "standard" templates to represent a wide range of weather factors, varying geographical locations and climatic conditions.

2. Player defined environmental effects which are defined at the process level and result in the variation of the time distributions associated with the work tasks of the process modeled.

The nature of the monitoring system is based on the observation of both project and process level flows and the measurement of their dynamic performance across time.

The interaction of the decision function and the effects of the environmental attack both acting on the original plan produce a <u>project status</u> or state which must be detected and monitored by a relevant management information system. At the project level monitoring is accomplished by a reporting scheme which audits the cumulative cost and time attributes of the system. At process level, the monitoring function reports on production and system delays and resource imbalance. Monitoring at both levels can be likened to the placement of measuring guages in a hydraulic system and the measurement of system flows. By reading these flow indicators, the player is able to determine the state of the system.

With the management decision cycle as a basis, the gaming environment places the student in a decision role and surrounds him with a dynamic surrogate environment which forces him to adopt an active management decision role. In this way, the immediacy and relevancy of problem confrontation in the construction management area is projected into the classroom situation.

This is in sharp contrast to the typical construction educational mold focusing on applied science courses and textbook format where computers, if used at all, are viewed only as calculational aids. Further, it is an advance over the uses of computers in the programmed educational sense where computers simply ask questions and correct wrong answers. A detailed discussion of all research findings and results is contained in Reference 3.

8. Publications:

a.) Halpin, D. W., H. Manescu, N. Tutos, and R. W. Woodhead, "Simulation Models as a Predictive Tool in Construction Management," Proc., Fourth International Congress on Project Planning by Network Techniques, Paris, France, October, 1974, pp. 285-289.

b.) Halpin, D. W., "CYCLONE - A Graphical Method for Simulation Modeling of Construction Operations," Proc., Second Inter-American Conference on Systems and Informatics, Mexico City, Mexico, November, 1974.

c.) Halpin, D. W. "Final Report - A Computerized Construction Management Gaming Environment," Technical Report SCEGIT-75-114, School of Civil Engineering, Georgia Institute of Technology, Atlanta, December, 1974, pp.257

d.) Halpin, D. W., "CONSTRUCTO - An Interactive Gaming Environment," Journal of the Construction Division, Vol. 102 No. CO1, March 1976.

e.) Halpin, D. W., "A Multi-Level Construction Game", Journal of the Construction Division, ASCE, (in preparation).

9. Thesis:

a.) Griffith, William L., "A Construction Equipment Management Game," M. S. Thesis, School of Civil Engineering Georgia Institute of Technology, Atlanta, Georgia, August, 1974.

10. Scientific Collaborators:

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11. Comments:

A proposal for extension of the Grant is in preparation.

12. Signature: Daniel W. Halpin

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References

1. Halpin, D. W. and R. W. Woodhead, CONSTRUCTO - A Heuristic Game for Construction Management, University of Illinois Press, Urbana, Illinois, March, 1973.

2. Halpin, D. W., "An Investigation into the Use of Simulation Networks for Modeling Construction Operations," Ph.D. Thesis, U. of Illinois, Urbana, Illinois, Spring, 1973.

3. Halpin, D. W., "Final Report - A Computerized Construction Management Gaming Environment," Technical Report SCEGIT-75-114, School of Civil Engineering, Georgia Institute of Technology, Atlanta, December, 1974.